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DESAL ION EXCHANGE FOR DEMINERALIZATION AT SANTEE, CALIFORNIA

Henry Filar, Jr.

Santee County Water District
Santee, California

May 1973

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DESAL ION EXCHANGE FOR DEMINERALIZATION AT SANTEE, CALIFORNIA

PB 220 123

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Grant No. WPRD 5-01-67
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16. Abstract

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The system was designed to demineralize a portion of the influent stream and blend it with influent water to make a product TDS equal to or better than the Colorado River drinking water supplied to Santee. Because of the short operating time, emphasis was placed on the demineralization process, especially the anion IRA-68 resin performance.

The estimated total cost, based on Santee, for 64,370 gpd of 500 mg/l (as $CaCO_3$) blended effluent is $1.00 per 1000 gallons. This estimate calls for activated carbon adsorption influent, two complete operating cycles per day, and a properly functioning blending system. (EPA)

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ABSTRACT

A 50,000 gpd Desal ion exchange pilot plant for the demineralization of lime treated, dual media filtered, tertiary effluent has been built and tested at Santee, California. The plant removed up to 86 percent of the total dissolved solids (TDS) as $CaCO_3$. Influent TDS ranged from 700 to 1000 mg/l during the two month operating period (All TDS values were the sum of the chloride, sulfate, and alkalinity concentrations as $CaCO_3$). Anion resin (45 cu ft of IRA-68) capacities of 11.4 and 9.7 Kgr (as $CaCO_3$)/ cu ft were obtained with a tertiary effluent flow of 1 gal./cu ft/min and an operating pressure of 40 psig.

The system was designed to demineralize a portion of the influent stream and blend it with influent water to make a product TDS equal to or better than the Colorado River drinking water supplied to Santee. Because of the short operating time, emphasis was placed on the demineralization process, especially the anion IRA-68 resin performance.

The estimated total cost, based on Santee, for 64,370 gpd of 500 mg/l (as $CaCO_3$) blended effluent is $1.00 per 1000 gallons. This estimate calls for activated carbon adsorption influent, two complete operating cycles per day, and a properly functioning blending system.

This report was submitted in fulfillment of Grant Number 5-01-67 under partial sponsorship of the Water Quality Office, Environmental Protection Agency by the Santee County Water District. Work was completed as of April 1973.

CONTENTS

Section		Page
I	Conclusions	1
II	Introduction	3
III	Plant Description	7
IV	Laboratory and Sampling Methods	15
V	Pretreatment	17
VI	Results and Discussion	21
VII	Cost Estimates	45
VIII	Acknowledgements	49
IX	References	51
X	Glossary	53
XI	Appendices	55

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FIGURES

Number		Page
1	FRONT VIEW OF THE DESAL ION EXCHANGE PLANT, SHOWING THE CONTROL PANEL	8
2	SIDE VIEW OF THE DESAL ION EXCHANGE PLANT, SHOWING THE CONTROL PANEL	8
3	SIDE VIEW OF THE DESAL ION EXCHANGE PLANT, SHOWING PNEUMATIC VALVES	9
4	FRONT VIEW OF THE CONTROL PANEL	9
5	STEPS 1 THROUGH 3 - BACKWASH	11
6	STEPS 4, 5, AND 6 - ACID AND AQUA AMMONIA INJECTION AND DISPLACEMENT	11
7	STEP 7 - FAST RINSE	12
8	STEP 7 ALTERED - CATION COLUMN FAST RINSE AND ANION COLUMN SLOW RINSE	12
9	STEPS 10 AND 11 - SERIES RINSE AND SERVICE, FORWARD	13
10	STEPS 10 AND 11 - SERIES RINSE AND SERVICE, REVERSE	13
11	DESAL ION EXCHANGE LAY-OUT, SHOWING TERTIARY FLOW PATTERN	18
12	FIRST SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE	27
13	SECOND SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE	28
14	THIRD SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE	30
15	PPM AS NACL OF THE DESAL ION EXCHANGE EFFLUENT FOR RUNS 11, 12, AND 13	31
16	INITIAL ANION COLUMN CHLORIDE LEAKAGE FOR RUNS 12 AND 13	33

FIGURES (continued)

Number		Page
17	FOURTH SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE	34
18	FIFTH SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE	36
19	INITIAL ANION COLUMN CHLORIDE LEAKAGE FOR THE FIRST RUN OF EACH SERIES	39

TABLES

Number		Page
1	Averages of the Major Cation and Anion Constituents in the Desal Ion Exchange Influent During the Project Period	19
2	Chemical Analysis of Anion Column 3 Drain Effluent	23
3	Flows and Cycle Step Time Lengths	24
4	Influent and Effluent Conductances with Total Product Gallonage and Run Capacities	29
5	Capacities and Service Flows for the Third and Fourth Series	32
6	Chloride Leakage at Shutoff and Gallons of Product Before Breakthrough	37
7	Chloride Leakage at Shutoff and Gallons of Product Before Breakthrough	37
8	Lead Anion Column Capacity and Gallons of Demineralized Water Before Breakthrough	40
9	Gallons of Demineralized Water Before Breakthrough and Capacities for Series 4 and 5	40
10	Run 2 Final Anion Column Hardness Leakage	42
11	Total Hardness and Total Gallons Fed into Storage Tank	43
12	Influent Parameters and Expected Capacities for the IRC-84 Resin	44
13	Capacities for Runs 5 and 6	44
14	Ion Exchange Cost Estimate Based on 64,370 Gallons 500 mg/l TDS Blended Effluent per Day	46

SECTION I

CONCLUSIONS

1. The Desal ion exchange pilot plant at Santee, California functioned automatically and demineralized lime treated tertiary effluent during the two month operating period.

2. The total dissolved solids (TDS) removal was up to 86 percent with an influent TDS ranging between 700-1000 mg/l as $CaCO_3$. TDS values were based on the sum of the chloride, sulfate, and alkalinity concentrations, as $CaCO_3$.

3. Anion resin (45 cu ft of IRA-68) capacities of 11.4 and 9.7 Kgr/cu ft (based on TDS as $CaCO_3$ removal) were obtained with a service flow rate of 1 gal./cu ft/min and a system operating pressure of 40 psig. Each cycle respectively produced 15,000 and 12,000 gallons of demineralized water.

4. The capacity of the anion IRA-68 resin, in the lead position, was the limiting factor in each run. This was because the IRA-68 exhausted before the cation IRC-84 resin.

5. The estimated total cost of Desal ion exchange demineralization for 64,370 gpd of 500 mg/l TDS as $CaCO_3$ blended effluent is $1.00 per 1000 gallons. This estimate requires activated carbon influent, two complete operating cycles per day, and a properly functioning blending system. The blending system was never operative at Santee.

6. Even with the mechanical difficulties, it is felt that the Desal process shows promise and that further work with the system is needed.

SECTION II

INTRODUCTION

A Desal ion exchange pilot demonstration project has been completed at Santee, California. The pilot plant study was conducted by Santee County Water District with the support of a research and development grant WPRD 5-01-67, from the Environmental Protection Agency. The unit was designed and engineered by a local Southern California firm, and constructed by a contractor using Arrowhead Puritas hardware. The project consisted of the demineralization of tertiary effluent using the Rohm and Haas Desal ion exchange process. The plant was designed to produce 50,000 gpd of blended effluent. The tertiary effluent used for feed water was to be lime treated, dual media filtered effluent, followed by activated carbon adsorption treatment. Difficulties in initiating the Desal plant operations, limited the project to a two month startup program. The operating phase was modified to demineralization studies on lime treated tertiary effluent without activated carbon adsorption treatment. The blending phase was eliminated from the study.

RECLAIMED WATER SYSTEM AT SANTEE, CALIFORNIA

The history of research at Santee, California has been documented in two previous reports, The Santee Recreation Project, Santee, California, Final Report (1) and Tertiary Treatment by Lime Addition at Santee, California (2). A brief summary of the research is as follows: In the early sixties, Santee reclaimed secondary effluent by percolating it through a layer of top soil and collecting it in a trench approximately 1,000 yards from the percolation ponds. The water then flowed down the trench into a series of man made community recreational lakes. This successful project received national attention and was sanctioned by the federal and state public health departments after extensive virus removal studies.

In 1966, studies were continued at Santee with the partial support of a demonstration grant from the Environmental Protection Agency (EPA). This project included the construction and operation of a 2 mgd lime tertiary treatment plant for the investigation and demonstration of actual costs, operational procedures, and effluent quality.

PILOT PLANTS

The demonstration grant by the EPA also included partial funding for a pilot Desal ion exchange study. This study was to be concurrrect with an EPA demonstration contract consisting of a 100,000 gpd activated carbon plant and a 50,000 gpd electrodialysis demineralizer. The remaining 50,000 gpd of activated carbon effluent was to have been fed to the Desal ion exchange plant. Operation of the activated carbon plant and the electrodialysis demineralizer began in January

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1970 and ended in June 1971. The results of this project can be found in Carbon Adsorption and Electrodialysis for Demineralization at Santee, California (3). The Desal ion exchange plant operated from 1 August 1971 until 1 October 1971, on demineralized lime treated tertiary effluent without carbon adsorption.

SCOPE OF WORK

The initial project objective was to compare the electrodialysis and the Desal ion exchange processes for demineralization of the same quality carbon effluent. However, problems in the ion exchange start-up (discussed in detail in the Results Section) prevented its continuous operation until August 1971. By this time the electrodialysis program had terminated and comparisons of the two processes on the same carbon effluent was not possible. Also, soon after the electrodialysis operations had terminated, most of the laboratory staff had left Santee; this limited any extensive chemical studies of the ion exchange process. Because of these factors, and with only two months remaining until the termination of the tertiary plant, the Desal ion exchange objectives were changed to maintaining operation and gathering information on resin capacities, in particular, the anion IRA-68 resin performance.

Since it has been reported that IRA-68 is not subject to extensive organic fouling, it was felt that useful information could be obtained using the lime treated tertiary effluent for the two month study period. It was also decided to concentrate on the carbonation and general performance of the anion column since earlier startup experience suggested that this would be the limiting performance resin.

DESCRIPTION OF THE DESAL PROCESS

The following is taken in part from a Rohm and Haas publication (4). The Rohm and Haas Desal process generally consists of a series of three units. The first unit, which is the alkalization unit, contains Amberlite IRA-68 in the bicarbonate form. When passing the influent through this unit, the anionic constituents are exchanged and the cation constituents are converted to the bicarbonate salts, for example, the exchange reaction for sodium chloride is:

$$(R\text{-}NH)\ HCO_3 + NaCl \rightarrow (R\text{-}NH)\ Cl + NaHCO_3 \text{ (alkalization)}$$

The second unit, or dealkalization unit, contains Amberlite IRC-84, a weak acid cation exchange resin. In this unit the bicarbonate salts are converted to carbonic acid by the exchange of cations for hydrogen, as denoted in the following equation:

$$R\text{-}COOH + NaHCO_3 \rightarrow R\text{-}COONa + CO_2 + H_2O \text{ (dealkalization)}$$

The third unit, which is the carbonation unit, also contains Amberlite IRA-68, but in the free base form. When in the free base form the Amberlite IRA-68 absorbs the carbonic acid from the effluent of the Amberlite IRC-84 unit as shown in the following equation:

$$R\text{-}N + H_2O + CO_2 \rightarrow (R\text{-}NH)\ HCO_3 \text{ (carbonation)}$$

Upon completion of the above exhaustion cycle, the alkalization unit is regenerated back to the free base form with ammonia hydroxide as illustrated in the following equation:

$$(R\text{-}NH)\ Cl + NH_4OH \rightarrow (R\text{-}N) + NH_4Cl + H_2O \text{ (anion column regeneration)}$$

The dealkalization unit is converted back to the hydrogen form by regeneration with sulfuric, hydrochloric, nitric, or sulfurous acid as illustrated in the following equation:

$$2RCOONa + H_2SO_4 \rightarrow 2RCOOH + Na_2SO_4 \text{ (cation column regeneration)}$$

Since the carbonation unit is already in the bicarbonate form, the flow pattern is reversed for the next cycle and the third unit becomes the alkalization unit and the first unit the carbonation unit.

Amberlite IRA-68 and the Amberlite IRC-84 typical properties are shown in Appendix A, Table 1.

SECTION III

PLANT DESCRIPTION

PLANT HARDWARE

The Santee Desal Ion Exchange plant was designed to operate one cycle per day and produce 50,000 gallons of product water quality equal to or better than the Colorado River drinking water supplied to the community. The unit was capable of operation in either the forward or reverse direction. Each of the three vessels was 10 feet in height and 42 inches in diameter, and designed for a maximum of 50 psig. The vessels and pilot plant are shown in Figures 1 and 2. Piping was scheduled 40 PVC with pocket type PVC fittings which were solvent welded. All tertiary and product water flowed through 3 inch piping. All acid and aqua ammonia injections, aqua ammonia rinses, and demineralized storage water flowed through 1 inch piping. The system valves were Saunders patent diaphragm type (air operated) with flanged PVC bodies. These valves were opened by an air signal. A side view of the plant with valves and piping is shown in Figure 3.

The control panel housed all instrumentation, timers, relays, solenoid valves, and cycle programmers. The cabinet was located outdoors, and can be seen in Figures 1 and 4. Air was supplied by an Ingresoll-Rand compressor supplied with a model 2 air dryer.

The 820 gallon sulfuric acid tank had 8 mils of baked phenolic resin internal coating. The 2000 gallon aqua ammonia tank had all welded construction and no internal coating. A storage supply of demineralized water was originally kept in an 850 gallon fiberglass tank. The level of the demineralized water in this storage tank was controlled by a Clayton automatic float valve.

Aqua ammonia was injected into a demineralized water stream by a simplex milroyal model A pump (4 gpm maximum). A simplex milroyal pump model A was used for the sulfuric acid injection. This pump had a maximum output of approximately 0.31 gpm. The original demineralized water centrifugal pump was an Aurora model E4 rated at 6 gpm at 100 ft TDH. The original ion exchange feed pump was an Aurora model, rated at 30 gpm at 80 ft TDH.

SANTEE DESIGN

The Santee unit was designed to be completely automatic. The Agastat programmers controlled the Grinnel-Saunder valves through regeneration, rinse, service, and standby. All regeneration and rinses, including series rinse, were definite pre-set time intervals. When the programmers advanced into the service step, water was immediately directed into the demineralized water storage tank. The Clayton automatic float valve shutoff the incoming water when the level reached approximately

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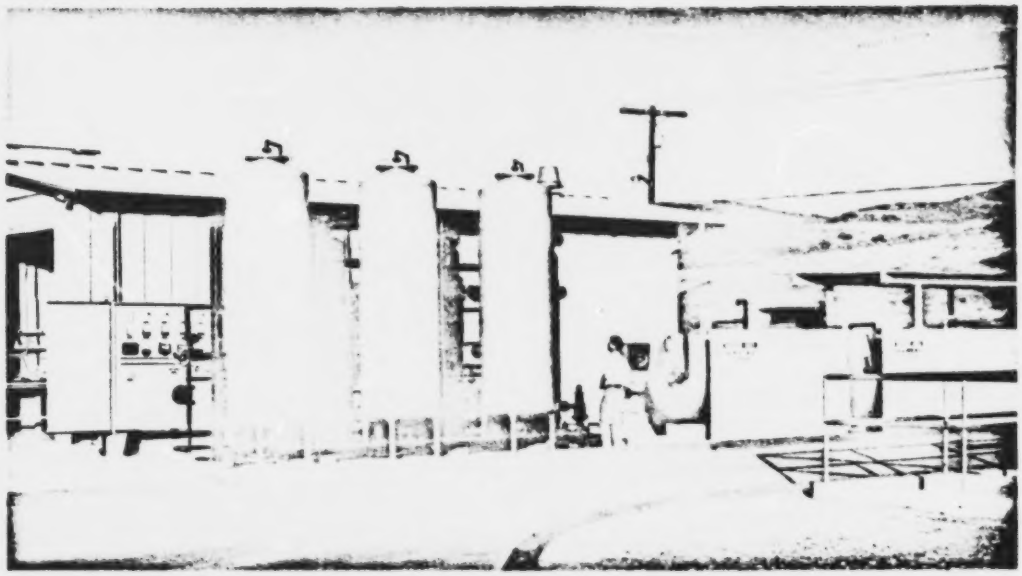

FIGURE 1. FRONT VIEW OF THE DESAL ION EXCHANGE PLANT, SHOWING THE CONTROL PANEL.

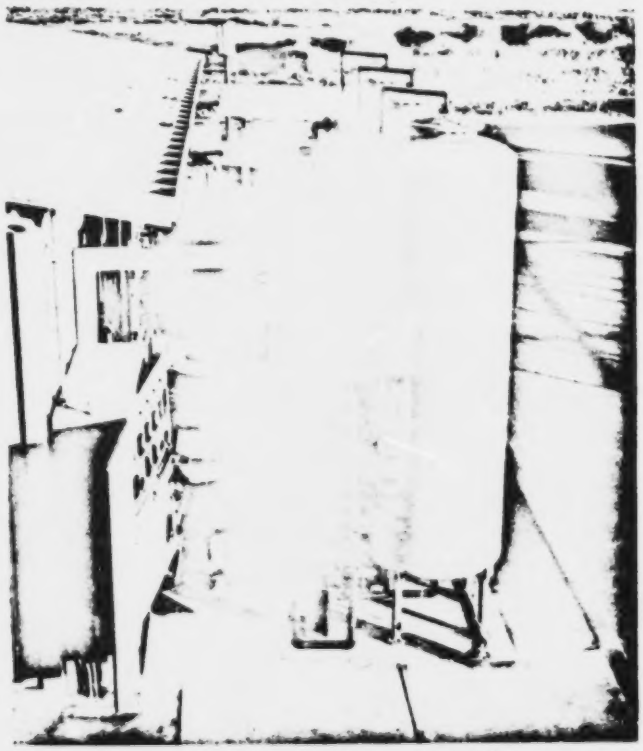

FIGURE 2. SIDE VIEW OF THE DESAL ION EXCHANGE, SHOWING THE CONTROL PANEL.

FIGURE 3. SIDE VIEW OF THE DESAL ION EXCHANGE PLANT, SHOWING PNEUMATIC VALVES.

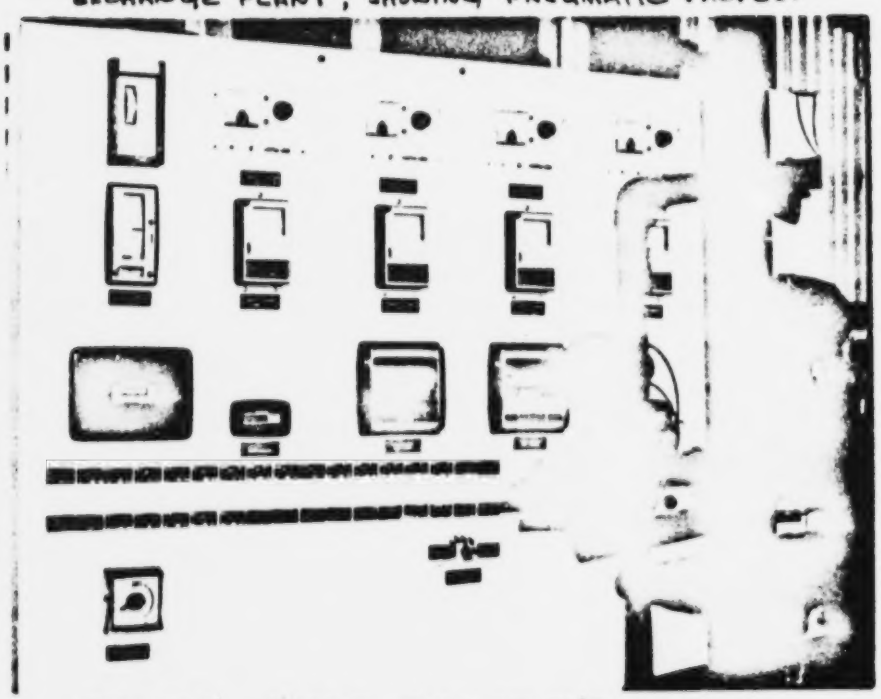

FIGURE 4. FRONT VIEW OF THE CONTROL PANEL.

500 gallons, and redirected the flow into the blending system where the product water was maintained at a pre-set conductance. Deltec conductivity meters coupled with Grinnel air motor diaphragm valves then controlled feed and demineralized water flows, and terminated the service step at a given conductance.

The automatic cycle was divided into twelve steps by the Agastat programmers. The time interval of each step was controlled by a separate timer. The cycle was identical both forward (columns 1-2-3) and reverse (columns 3-2-1).

Steps 1 through 3 backwashed each column. Backwashes used upflow tertiary water and were performed every cycle (Figure 5). Step 4 injected sulfuric acid and aqua ammonia into their proper columns (Figure 6). Sulfuric acid was injected at a constant rate into the tertiary water stream before entering the cation column; the concentration of the solution contacting the resin bed was controlled by the stepless acid regeneration assembly using a Grinnel air motor valve to regulate the diluting tertiary water flow. Simultaneously, aqua ammonia was injected into anion column 3 or anion column 1, depending on the direction of the succeeding service step (forward or reverse). Demineralized water was used for the aqua ammonia dilution. Step 5 initiated the displacement of aqua ammonia in the anion column by demineralized water, and continued the acid injection into the cation column at the highest concentration determined by the stepless acid assembly. Step 6 continued aqua ammonia displacement with demineralized water, and initiated sulfuric acid displacement with tertiary water. This tertiary water flow was quickly brought back up to its maximum by the stepless acid regenerant assembly. Flow patterns for steps 4, 5, and 6 are shown in Figure 6. Step 7 originally initiated the fast rinse of both the cation and the anion column using tertiary water (Figure 7). This step was later altered to eliminate the contact of tertiary water with the regenerated anion columns (IRA-68), and was substituted with a continuation of the slow rinse in steps 5 and 6, (Figure 8). Steps 8 and 9 were exactly as step 7: they were present in order to take up two faces of the twelve faced Agastat programmers. Both step 8 and step 9 were two minutes long. Series rinse began when the Agastat programmer advanced into step 10. Flow patterns, forward and reverse, are shown in Figures 5 and 6. The service cycle was initiated in step 11, forward and reverse flows are also shown in Figures 9 and 10. The product flow was directed either into the demineralized water storage tank or into the blending system.

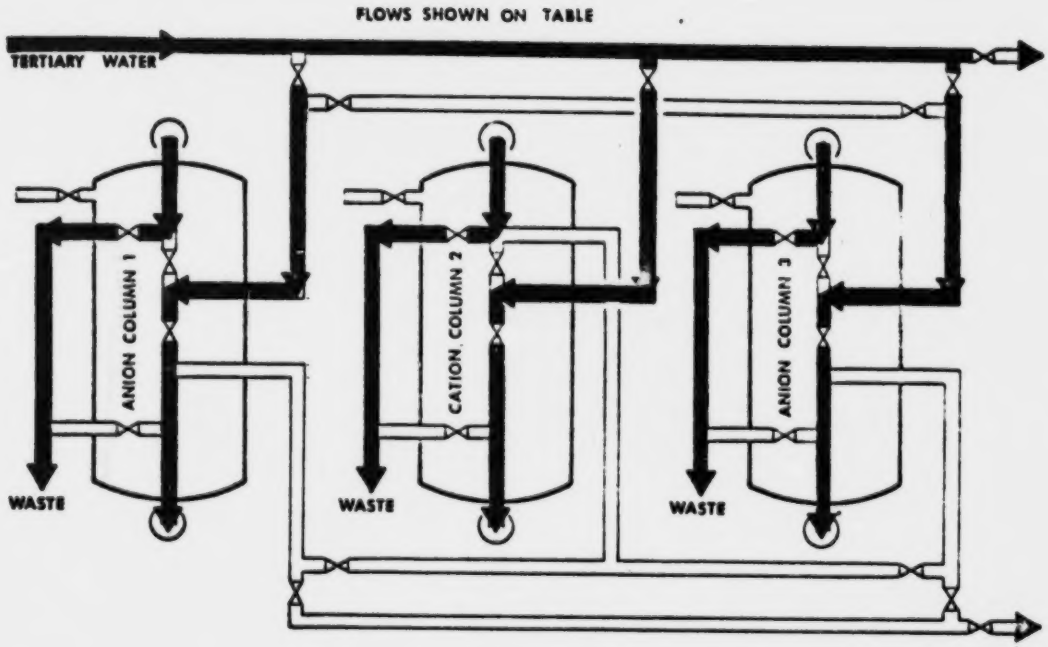

Figure 5. STEPS 1 THROUGH 3 - BACKWASH

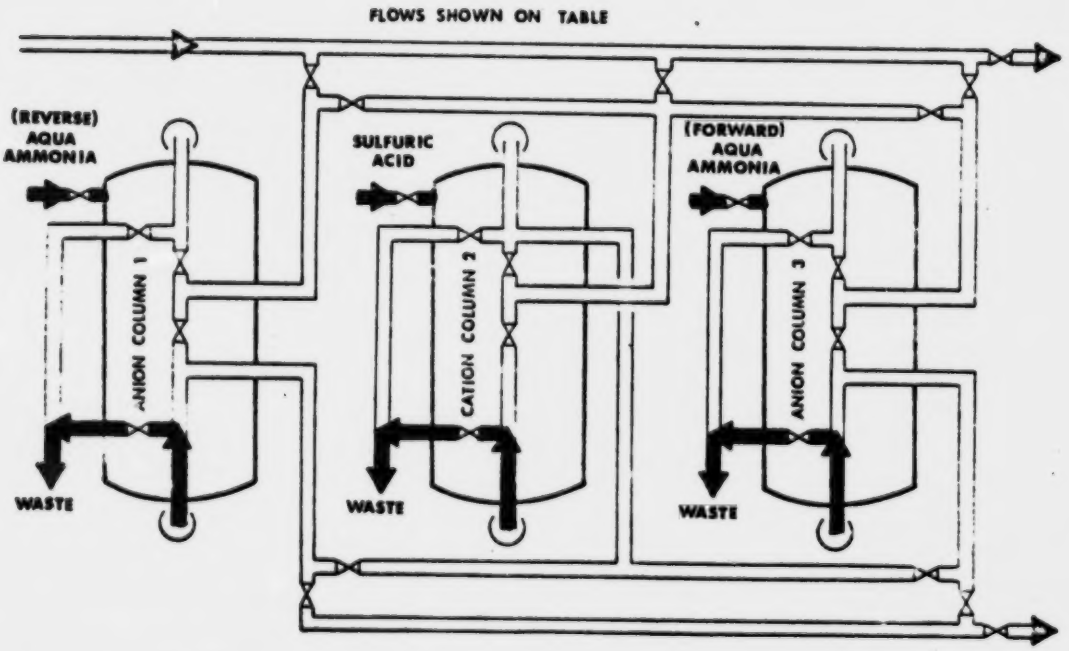

Figure 6. STEPS 4, 5 AND 6 - ACID AND AQUA AMMONIA INJECTION AND DISPLACEMENT

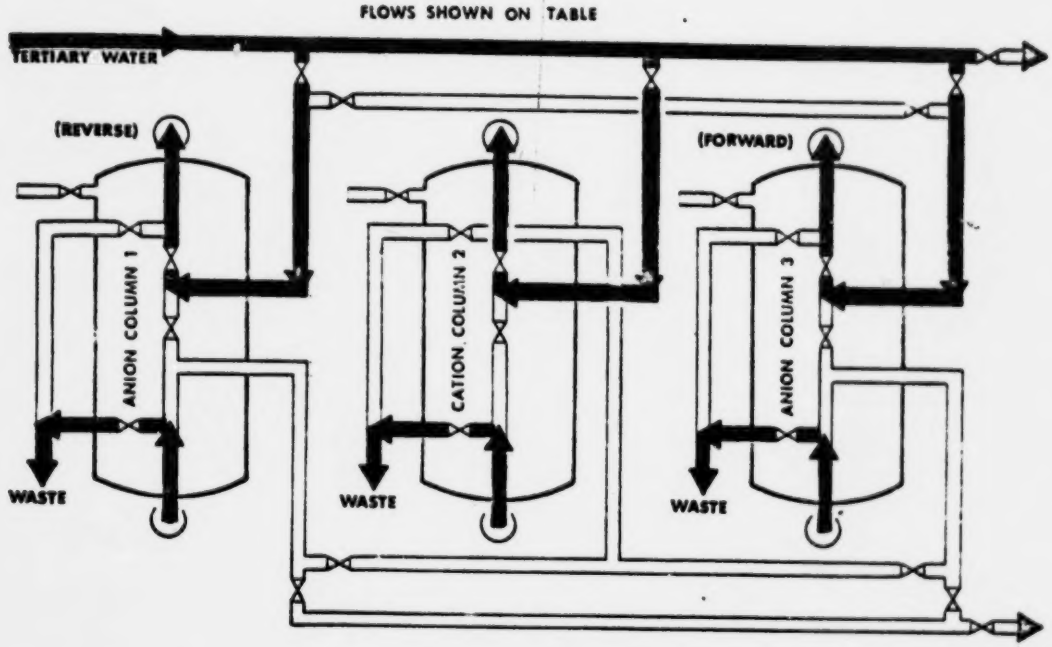

Figure 7. STEP 7 - FAST RINSE

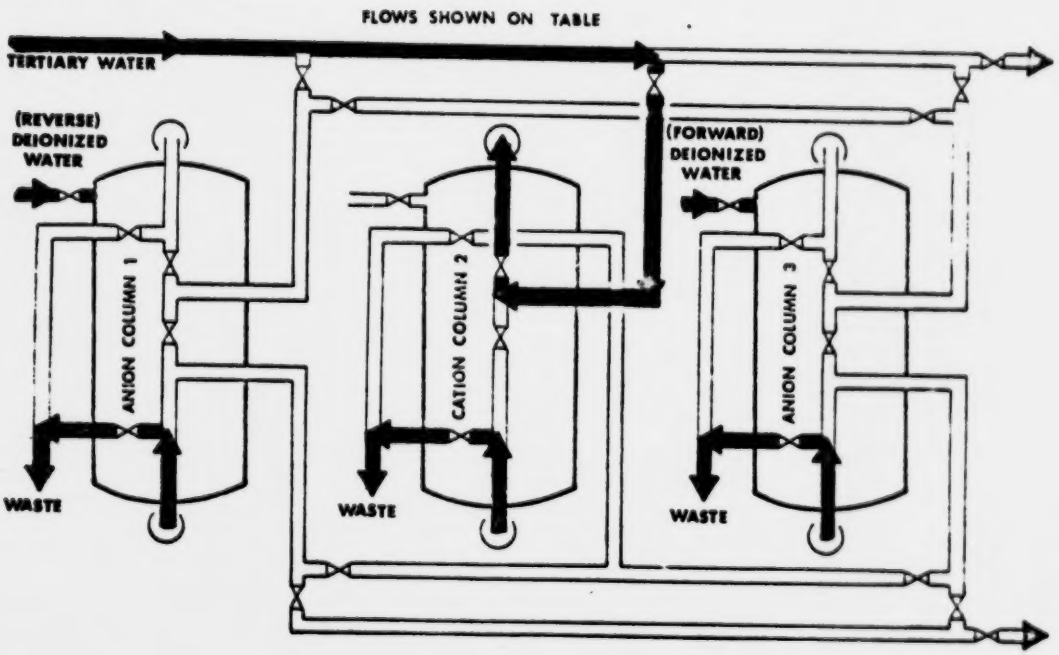

Figure 8. STEP 7 ALTERED - CATION COLUMN FAST RINSE AND ANION COLUMN SLOW RINSE

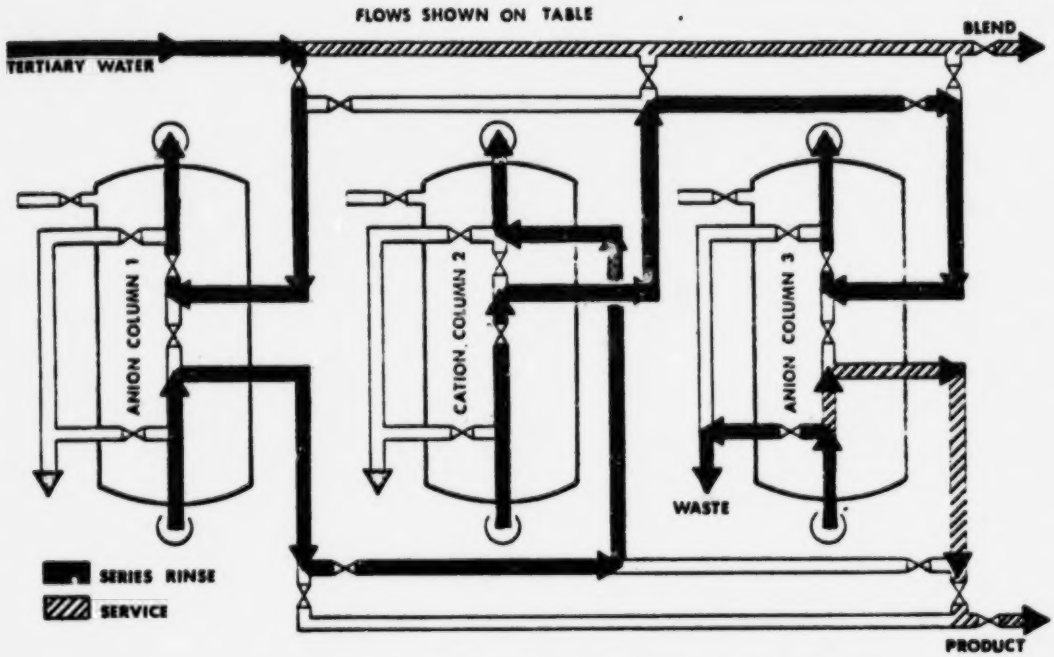

Figure 9. STEPS 10 AND 11 - SERIES RINSE AND SERVICE FORWARD

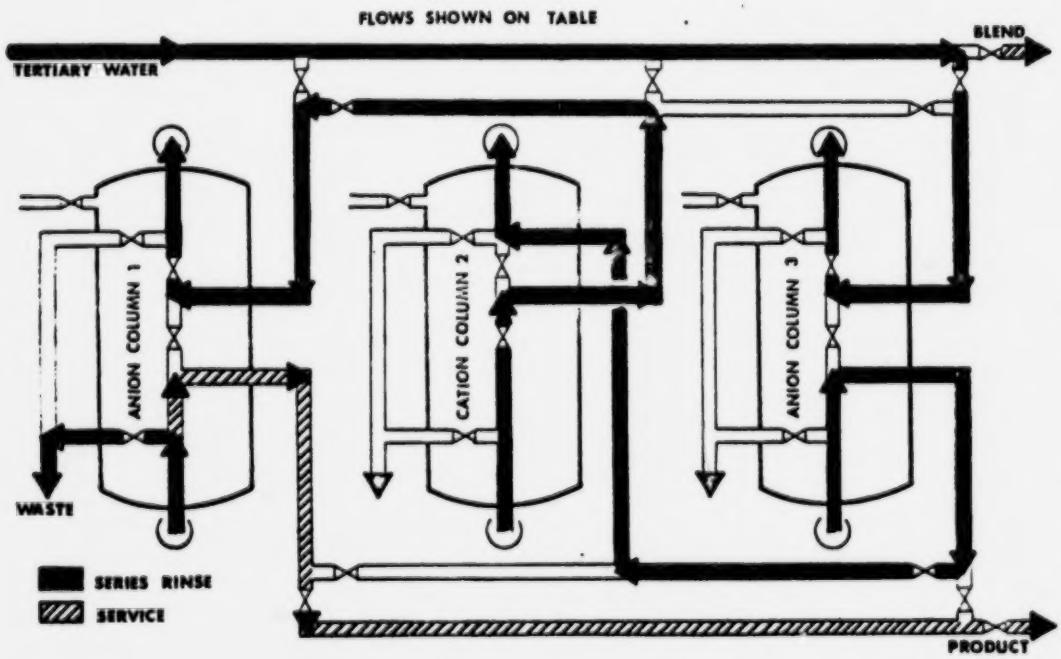

Figure 10. STEPS 10 AND 11 - SERIES RINSE AND SERVICE REVERSE

SECTION IV

LABORATORY AND SAMPLING METHODS

SAMPLING

All chemical analysis were carried out on grab samples taken directly from the respective streams. The progress of the runs were monitored by collecting one liter samples at various intervals. Upon collection, the bottles were immediately capped and taken to the laboratory for sample analysis.

LABORATORY

Laboratory work before 16 August 1971 was performed by Santee Laboratory personnel. After 16 August 1971, starting with Run 8, all chemical and project work was done only by the investigator.

All methods were taken from the 1965 Standard Methods (5). A Photovolt Model 115 pH meter was used for pH and alkalinity measurements (Potentiometric titration). A Lab-line Model MC-1 conductivity meter was used for specific conductance measurements. Sulfates were measured using the Model B Spectrophotometer and the turbidimetric method. Total hardness concentrations were measured using the EDTA titration method. A model 290B Perkin-Elmer Atomic Absorption unit was used for sodium and potassium determinations.

A change in Chloride analysis occurred near mid-project. Chloride concentrations up to Run 9 were followed on a specific ion meter. The chemical analysis for Runs 1 through 9 (Appendix B, Tables 1 - 22), show a decrease in influent chloride concentrations not representative of the actual Santee tertiary effluent. Because of this divergence, the mohr method for chloride determinations was used for Runs 10 through 22.

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SECTION V

PRETREATMENT

SECONDARY TREATMENT

The secondary sewage plant at Santee was designed for a maximum of 4 mgd. During the ion exchange project, the plant treated an average 2 mgd. From 1 to 1.5 mgd of the secondary effluent was further treated in the lime tertiary plant. The remaining secondary effluent was stored in a large holding pond or lagoon following the main plant. The general flow pattern is shown in Figure 11.

TERTIARY TREATMENT

The secondary effluent was first treated with lime in a solids contact reactor-clarifier. The lime treated water was then gravity fed from the top of the reactor-clarifier into a carbonation unit where it was pH adjusted. One of two dual media (antracite-sand) gravity fed filters then polished the tertiary effluent. A portion of this effluent supplied the Desal ion exchange plant. The remaining effluent flowed into a separate lagoon.

Averaged values of the dual media filter effluent major cations and anions, are given in Table 1. All the concentrations, except total phosphate and orthophosphate, were averages of Desal influent grab samples taken during each run. Total phosphate and orthophosphate were averages of grab samples used to monitor the dual media sand filters from the report, Tertiary Treatment by Lime Addition at Santee, California (2).

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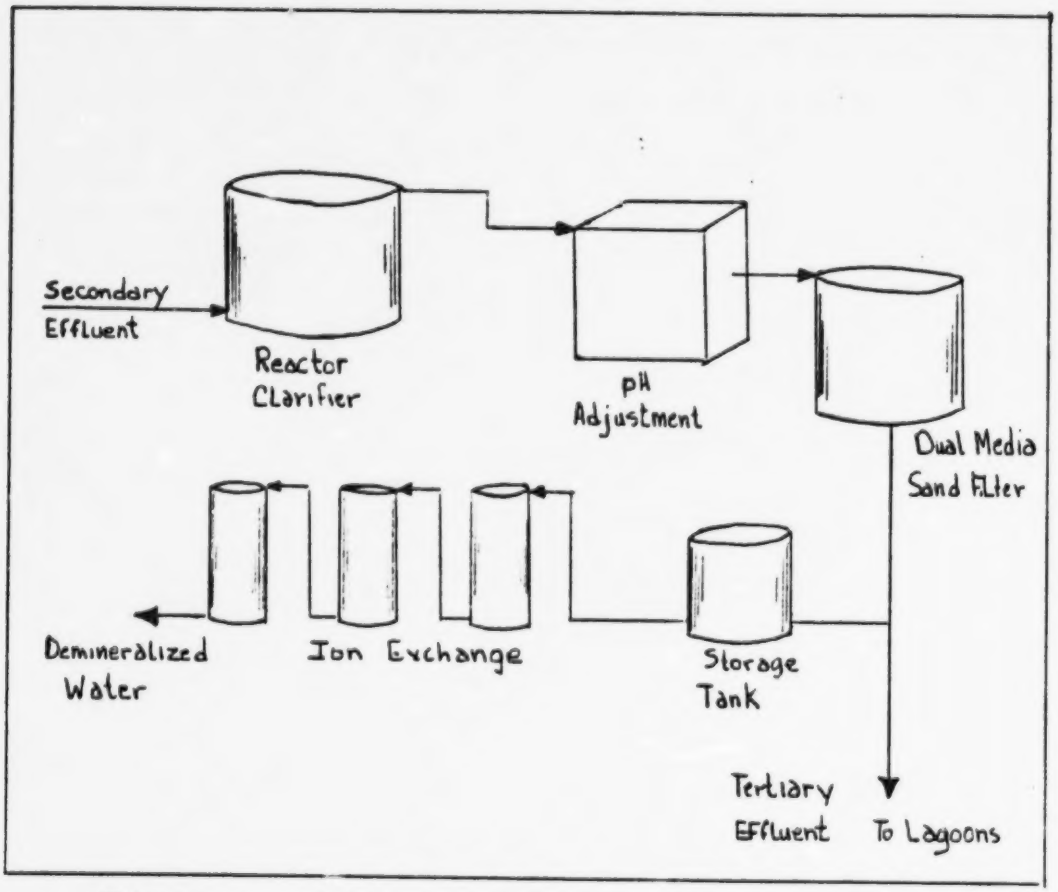

FIGURE 11.. DESAL ION EXCHANGE LAY-OUT. SHOWING TERTIARY FLOW PATTERN.

TABLE 1. AVERAGES OF THE MAJOR CATION AND ANION CONSTITUENTS IN THE DESAL ION EXCHANGE INFLUENT DURING THE PROJECT PERIOD.

Ionic Constituent	Average as mg/l
Alkalinity as $CaCO_3$	152
Chloride as Cl	206
Sulfate as SO_4	349
Total Phosphate as P	0.208
Ortho Phosphate filtrate as P	0.08
Total Hardness as $CaCO_3$	299
Sodium as Na	233
Potassium as K	21
pH, units	6.4

SECTION VI

RESULTS AND DISCUSSION

PERIODS OF OPERATIONS

Studies on the Desal ion exchange were divided into two periods. The first period, from January 1970 until August 1971, was designated the Initial Startup Period. Arrowhead Puritas corrected all obvious mechanical problems and maintained the basic process operation during this time. In the second period, from 1 August 1971 to 1 October 1971, the Desal plant was turned over to Santee and project research carried out.

INITIAL STARTUP PERIOD

Arrowhead Puritas began unit startup in January 1970. Insufficient flows were evident from the beginning: the feed pump had a flow of approximately 20 gpm on the Foxboro Flowmeter, and the demineralized water pump a working flow of 5-6 gpm. Two full scale runs were attempted with complete carbonation and regeneration. Both runs gave insufficient demineralizations. Inspection of the vessel insides disclosed that the laterals and distribution piping of the anion columns were plugged with a magnesium hydroxide precipitate. The precipitate was also easily visible on the surface of the IRA-68 beds.

After close analysis, it became evident that the magnesium hydroxide had precipitated in the distribution systems and on the resin beds when tertiary water was used for the dilution, displacement, and fast rinse of the anion columns had come in contact with the IRA-68 resin in the free base-form. The problem was aggravated by the low flow of the demineralized water pump (5-6 gpm), and the small storage capacity of the demineralized water tank. This tank held only 300 working gallons, which limited the water available for the slow rinse of Steps 5 and 6 (Figure 6).

All the regeneration distribution systems were removed, cleaned with hydrochloric acid, and reinstalled. The resin beds were then rinsed with hydrochloric acid and deionized water from small units brought in by Arrowhead Puritas. This rinse accomplished complete IRA-68 conversion to the chloride form and dissolved the magnesium hydroxide precipitate. The columns were rinsed with deionized water until the effluent indicated no trace of hardness. In order to prevent another precipitation, the tertiary water used for aqua ammonia dilution and displacement was eliminated and replaced with either soft or demineralized water. However, this no-hardness rinse was again limited by the small storage capacity of the demineralized water tank.

The system was regenerated, using the new rinse-cycle. The anion column 3 was then carbonated by injecting carbon dioxide into a

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demineralized water stream which passed through the resin bed and returned to the demineralized water storage tank. The subsequent forward service cycle gave the first indication of ion exchange by the system: the lowest value of the product water was approximately 283 micromhos/cm with a 1570 micromhos/cm at 25°C feed water. The run produced 7200 gallons of demineralized water; this was approximately 50 percent of the design 15,000 gallon production rate.

Poor carbonation was thought responsible for the insufficient demineralization of the tertiary water. Rohm and Haas felt the method of IRA-68 carbonation previously used, resulted in low conversion to the bicarbonate form. Carbon dioxide, up to this point, had been injected at 60 psig into a demineralized water stream (5-6 gpm). This stream flowed through the resin bed and discharged into the demineralized water storage tank at atmospheric pressure. The atmospheric back pressure adversely affected the carbon dioxide-resin equalibrium, $R\text{-}N + H_2O + CO_2 \rightleftharpoons (R\text{-}NH)HCO_3$, and allowed the gas to escape from the stream.

In order to maintain a back pressure, the demineralized stream was recirculated back to the feed pump. Carbon dioxide was then injected into the stream as close to 100 psig as possible. This carbonation was attempted after the final anion column (IRA-68) had been regenerated with 150 percent of the stoichiometric amount of aqua ammonia. Problems soon developed because of the 100 psig injection pressure. This pressure was greater than the "dead head" pressure of the demineralized water pump, and soon the closed system reached a static condition where all flow ceased. The flow was restored by periodically discharging the carbon dioxide entrapped in the top of the column through the air vent valve. This reduced the system pressure and started the flow. An excess of carbon dioxide was injected to replace that lost through the air vent valve.

The service run following the higher aqua ammonia regeneration and modified carbonation produced no demineralized water. Since it was apparent that carbon dioxide was getting to the resin bed, Rohm and Haas proposed that magnesium hydroxide was still present after the aqua ammonia regeneration, and that magnesium carbonate was interferring with the bicarbonate-free base ion exchange. At this time, the lead anion column had set for about one month in the bicarbonate form. Since only soft water had come in contact with the resin during the previous service cycle, Rohm and Haas proposed that chemical analysis of the column effluent would present a good picture of the equalibrium conditions existing in the vessel. Table 2 shows the results of these analysis; samples of the draining effluent were taken every 15 minutes.

TABLE 2. CHEMICAL ANALYSIS OF ANION COLUMN 3 DRAIN EFFLUENT.

Minutes	15	30	45
pH	9.4	9.35	9.5
Ca	14.4	10.4	8.0
mg	2.0	1.0	1.5
TH	44	30	26

Rohm and Haas also stated that the low demineralized water injection and rinse flow rates caused "channeling" and "hide out" in the IRA-68 resin bed. Because of the channeling, pockets of hardness still remained after the hydrochloric acid rinse. This hydraulic problem of low flow was observed by the Arrowhead Puritas representative early in the startup period. As he stated in his summation report:

> The Anion columns are 42" in diameter containing 45 cubic feet of exchange resin. The distribution of the 5.4 gallons per minute of water flow over the surface area of the column of 9.6 square feet presents very serious hydraulic problems...(6).

In order to prevent further precipitation of magnesium, the fast rinse of the anion column was eliminated and substituted with a continuation of the slow rinse using demineralized water. In order to remedy this "channeling" and "hide out" problem, pump changes were made. In early February 1971 the demineralized water pump was removed and the existing feed pump rated at 30 gpm at 80 ft TDH was shifted into its place. A new pump rated at 60 gpm was then installed as the new ion exchange feed pump, and the 850 gallon demineralized water storage tank replaced with a 5000 gallon fiberglass tank.

In early March 1971, the whole resin system was extensively flushed in order to completely remove the accumulated hardness. After again cleaning the distribution system in anion column 1, hydrochloric acid diluted with soft water was used in a series rinse of the unit (flow pattern in Figure 9) until the incoming pH was equal to the outgoing pH. This was followed by two more series rinses, first, with soft water and then with deionized water. Regeneration of the columns was then carried out using the new pumps. Flows, aqua ammonia, and acid injection are shown on Table 3, Run 1. Anion Column 1 was rinsed with soft water until no ammonia smell was detected, and then carbonated, using the closed system, with 236 pounds carbon dioxide.

TABLE 3. FLOWS AND CYCLE STEP TIME LENGTHS.

Step Number	Backwash 1	Backwash 2	Backwash 3	Regeneration 4		Regeneration 4		Regeneration 5		
	Column 1 gpm	Column 2 gpm	Column 3 gpm	Ammonia lb /min	Demineralized Water (DW) gpm	Sulfuric Acid lb /min	Tertiary Water (TW) gpm	Displace NH_3 (DW) gpm	Sulfuric Acid lb /min	Tertiary Water gpm
Step Time Min	10	10	10	25		25		29		
Run Number										
1	30	30	30	5.5	21	2.1	35-18	21	2.1	18
2	30	30	30	5.5	21	2.1	35-18	21	2.1	18
3	30	30	30	5.5	21	2.1	35-18	21	2.1	18
4	30	30	30	5.5	21	2.1	35-18	21	2.1	18
Step Time Min	10	10	10	25		25		58		
Run Number										
5	30	30	30	5.5	21	1.8	35-30	21	1.8	30
6	30	30	30	5.5	21	1.8	36-31	21	1.8	31
7	30	30	30	5.5	22	1.8	40-34	22	1.8	34
8	30	30	30	5.5	23	1.8	39-34	23	1.8	34
9	30	30	30	5.5	21	1.8	40-34	21	1.8	34
10	30	30	30	5.5	24	1.8	37-33	24	1.8	33
11	30	30	30	5.5	21	1.8	40-35	21	1.8	35
12	40	40	40	5.5	21	1.8	56-46	21	1.8	46
13	30	35	30	5.5	21	1.8	56-46	21	1.8	46
14	30	35	30	5.5	18	1.8	56-29	18	1.8	29
15	30	35	30	5.5	21	1.8	56-17	21	1.8	17
16	30	35	30	5.5	21	1.8	58-17	21	1.8	17
17	30	35	30	5.5	21	1.8	58-29	21	1.8	29
18	30	35	30	5.5	21	1.8	58-44	21	1.8	44
19	30	35	30	5.5	21	1.8	58-44	21	1.8	44
20	30	35	30	5.5	21	1.8	58-43	21	1.8	43
21	30	35	30	5.5	21	1.8	58-40	21	1.8	40
22	30	35	30	5.5	21	1.8	58-40	21	1.8	40

TABLE 3. FLOWS AND CYCLE STEP TIME LENGTHS (continued)

R I N S E

Step Number	6		7, 8, 9		10		11		
	Displace Ammonia (DW) gpm	Displace Acid (TW) gpm	Displace Ammonia (DW) gpm	Rinse Acid (TW) gpm	Series Rinse gpm	Time in Min	Service gpm	Total Gallons	CO_2 Injection lbs
Step Time Min	20		80						
Run Number									
1	21	18-35	21	29	21	---	21	9,600	---
2	21	18-35	21	29	21	---	21	8,400	---
3	21	18-35	21	29	21	---	21	10,320	---
4	21	18-35	21	29	21	---	21	---	---
Step Time Min	25		40						
Run Number									
5	21	30-35	21	29	19	95	19	6,650	12.0
6	21	31-35	21	29	19	119	19	7,260	11.0
7	22	34-38	22	29	18	---	18	6,740	14.3
8	23	34-38	23	29	17	80	17	7,270	25.3
9	21	34-39	21	29	17	100	17	9,290	21.5
10	24	33-36	24	29	18	---	18	5,240	8.1
11	21	35-38	21	29	18	107	18	8,020	10.5
12	21	46-56	21	70	48	58	48	6,170	20.5
13	21	46-56	21	70	48	81	48	12,420	9.0
14	18	29-56	18	31	42	56	42	9,500	10.0
15	21	17-56	21	58	43	52	43	13,090	9.0
16	21	17-58	21	58	44	45	44	11,000	10.0
17	21	29-58	21	58	45	---	45	13,230	7.0
18	21	44-58	21	58	41	97	41	8,560	7.0
19	21	44-58	21	58	43	65	43	6,700	7.0
20	21	43-58	21	58	49	55	49	15,060	16.0
21	21	40-58	21	58	44	54	44	13,000	11.0
22	21	40-58	21	58	38	29	38	12,140	8.0

Chemical data for Run 1 can be found on Table 1, Appendix B and flows, pressures, and total gallons at sample times are recorded on Table 1, Appendix C.

PROJECT WORK

Arrowhead Puritas controlled all unit operations during Runs 1 through 4. Final mechanical adjustments and operator instructions were made in this time. The first run was in a reverse direction (Columns 3-2-1) with carbon dioxide being injected into the service stream. Figure 12 shows lead anion column effluent chlorides versus gallons of product for Runs 1, 2, and 3. No data were recorded for Run 4, although, it gave water quality which never fell below 80 ppm as NaCl on the Deltec conductivity meter.

After Run 4, on 3 August 1971, Santee began Desal project work. At this time the sulfuric acid flow rate was reduced from 2.1 to 1.8 lbs/min and some injection and displacement time lengths were re-adjusted. These changes increased the sulfuric acid regeneration from 16.6 to 21.8 Kgr (as $CaCO_3$)/cu ft of resin (in this report, Kgr is always given as $CaCO_3$), yet lowered the acid concentration throughout injection. Refer to Table 3.

In the first series of runs, the objective was to operate the unit in a forward and reverse direction until the resins were expended. Anion column 3 was pre-carbonated with 50 pounds of carbon dioxide. Carbonation was maintained during the series by injecting carbon dioxide into the service influent stream. The lead anion column chloride leakages for Runs 5 through 8 are shown in Figure 13. The curves were shortened because the service cycle was automatically shutoff when the Deltec conductivity meter registered 50 ppm as NaCl. Service flows for the series were around 0.42 gal./cu ft/min. Lead anion column capacities for the respective runs were 5.1, 5.1, 5.0 and 4.2 Kgr/cu ft of resin, well below the design 14.5 Kgr/cu ft. The series was terminated after Run 8.

Loss of carbon dioxide because of the 50 ppm (as NaCl) service cycle shutoff point, and low final column outlet pressures, between 12 and 20 psig, were felt responsible for the low capacities of Runs 5 through 8. In the next series of turn-around runs, the outlet pressure of the final column was held at 30 psig, and termination of the service step was held until the lead anion column influent and effluent chlorides were of equal concentration. This shutoff point coincided with approximately 360 micromhos/cm in the product stream.

In preparation for the next series, Runs 9 through 12, column 3 was again carbonated with 50 pounds of carbon dioxide. As in the previous carbonation, the carbon dioxide was injected into a recirculating stream of demineralized water. Initial lead anion column capacities for this series were near 7 Kgr/cu ft compared to 5 Kgr/cu ft for

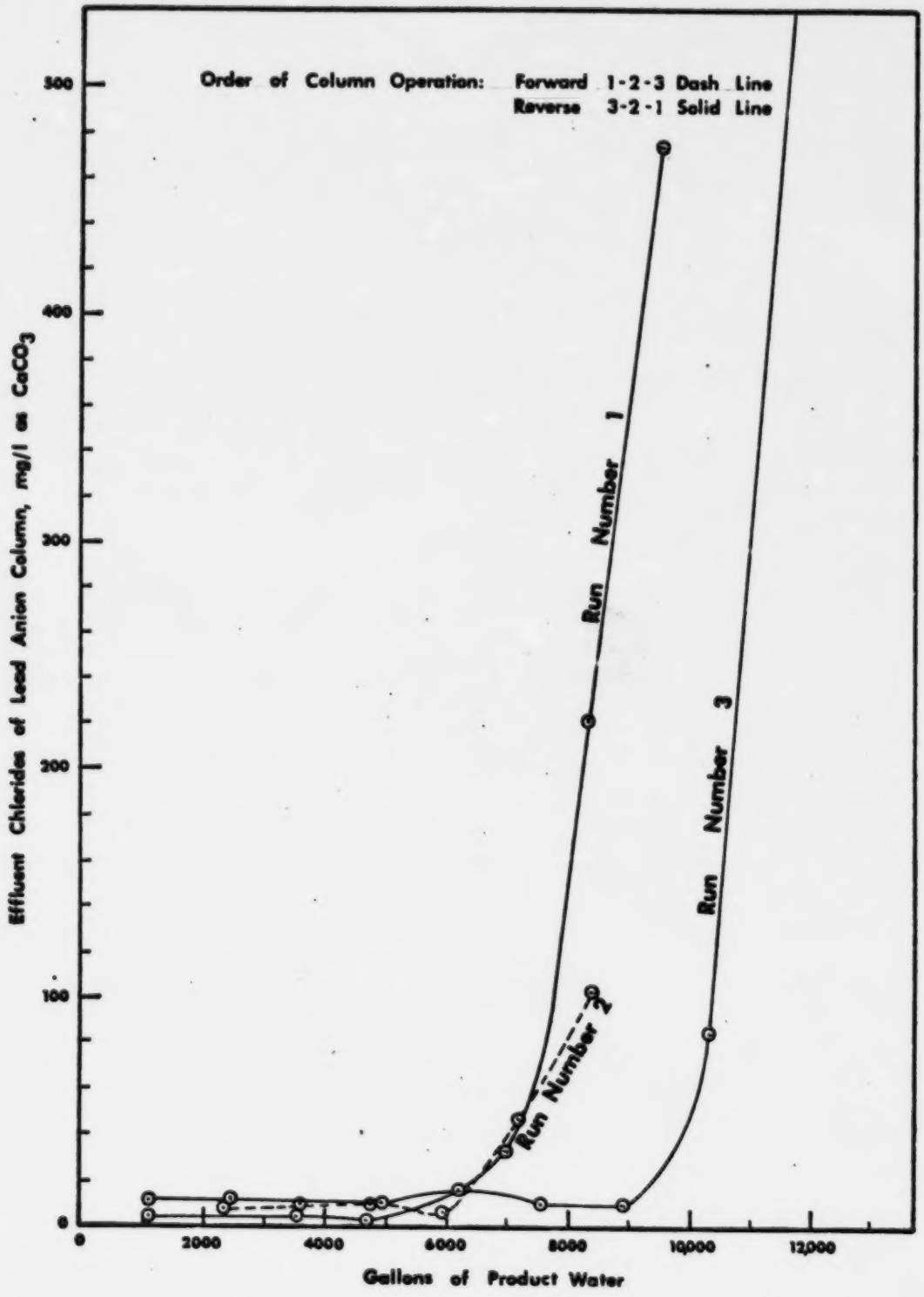

FIGURE 12. FIRST SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE

initial capacity in the previous series. Capacities are given in Table 4. Run 10 had an unusually low capacity because of electrical failures in the regeneration and service cycles. As the series progressed, the lead anion column chloride leakage increased. This is shown in Figure 14.

Actual flow rates up to Run 11 ranged from 17 to 21 gpm or 0.42-0.47 gal./cu ft/min. These values were half of the Rohm and Haas recommended minimum service flow rates. In order to bring the service flow up to the recommended rates, a new ion exchange feed pump rated at 50 gpm at 160 TDH was installed. The turn-around series in progress was continued (Run 12) using the higher service flow rate of 47.5 gpm (1 gal./cu ft/min). Lead anion effluent chlorides in Figure 14 show the affect of the increased flow rate on the chloride removal. The Rustrac recorder charts in Figure 15 illustrate the shortening of the service cycle.

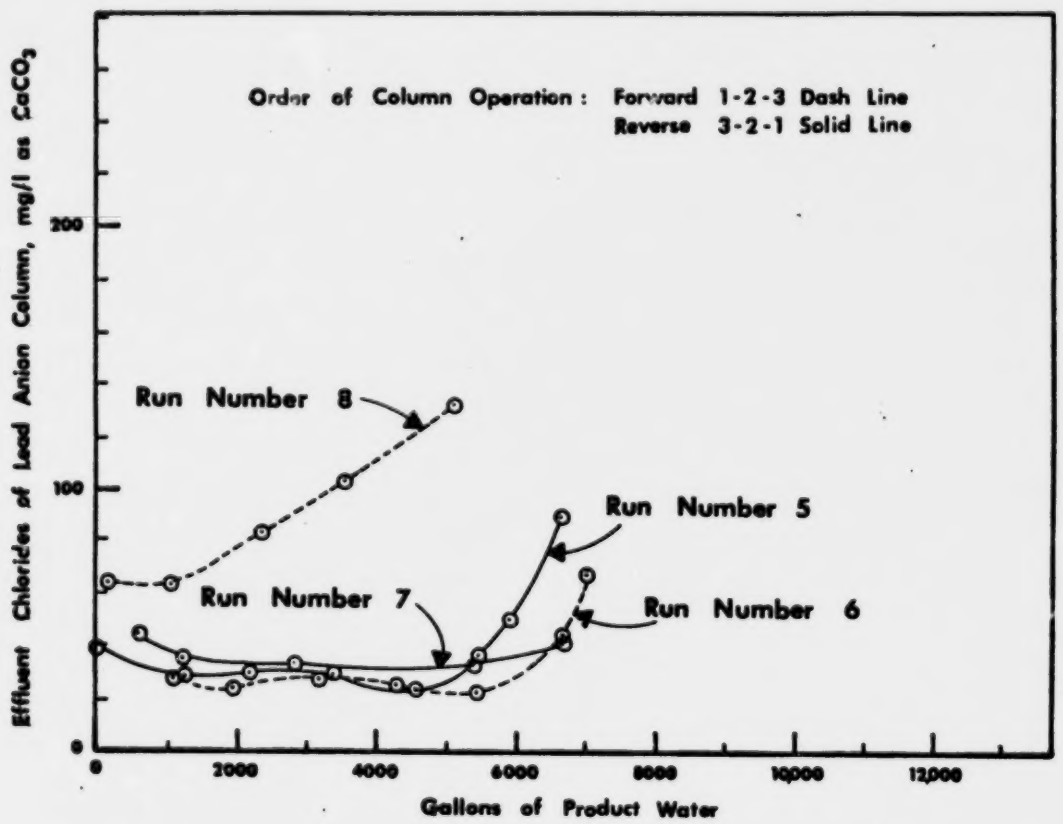

FIGURE 13. SECOND SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE.

TABLE 4. INFLUENT AND EFFLUENT CONDUCTANCES WITH TOTAL PRODUCT GALLONAGE AND RUN CAPACITIES.

Run Number	Unit micromhos/cm Range		Total Product Gallons	Pounds(as $CaCO_3$)Removed	Kgr as $CaCO_3$/45 cu ft	
	Influent	Effluent			Anion Column 1	Anion Column 3
1	1749-1642	634- 32	9,600	---	---	---
2	1710-1670	120- 40	8,400	---	---	---
3	1400- 950	650- 32	10,320	---	---	---
4	No Data	---	---	---	---	---
5	1736-1380	201- 92	6,650	32.5	---	5.1
6	1656-1472	360-167	7,160	32.9	5.1	
7	1862-1755	359-144	6,740	32.4		5.0
8	1794-1673	360-232	7,270	26.9	4.2	
9	1633-1547	360- 86	9,290	48.6		7.3
10	1706-1566	360-102	5,240	24.8	3.9	
11	1667-1601	392-178	8,020	34.9		7.0
12	1687-1620	870-295	6,170	35.6	5.4	
13	1641-1525	755-346	12,420	30.0		4.7
14	1658-1499	715-196	9,500	47.1	7.3	
15	1653-1596	360-126	13,090	60.7		9.5
16	1632-1570	349-200	11,000	44.8	7.0	
17	1620-1570	390-198	13,230	59.4		9.3
18	1680-1648	683-254	8,560	23.7	3.7	
19	1810-1530	419-149	6,700	42.0		6.5
20	1789-1633	468-156	15,060	73.2	11.4	
21	1683-1490	360-187	13,000	62.5		9.7
22	1642-1570	365-146	12,240	55.2	8.6	

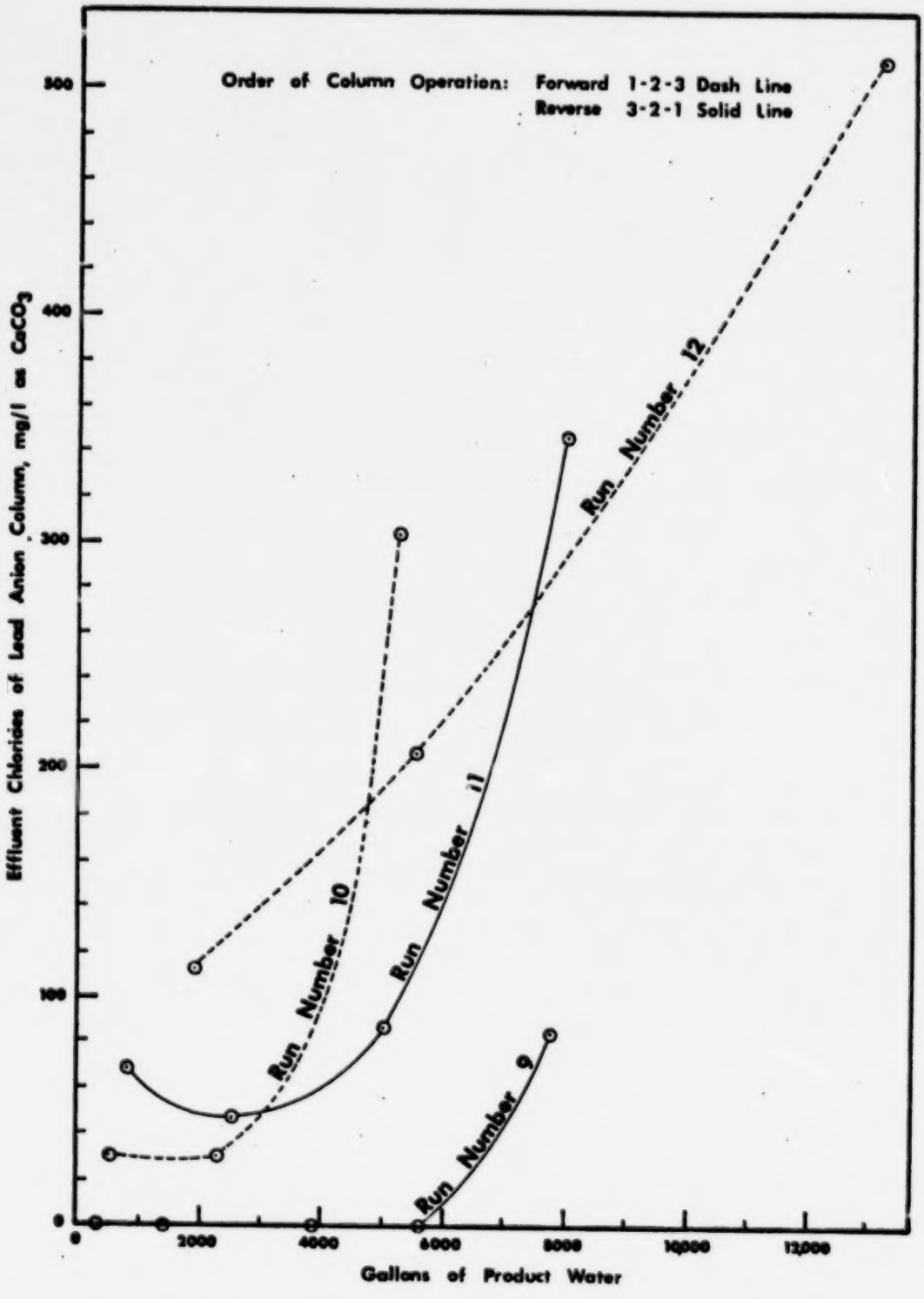

FIGURE 14. THIRD SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE.

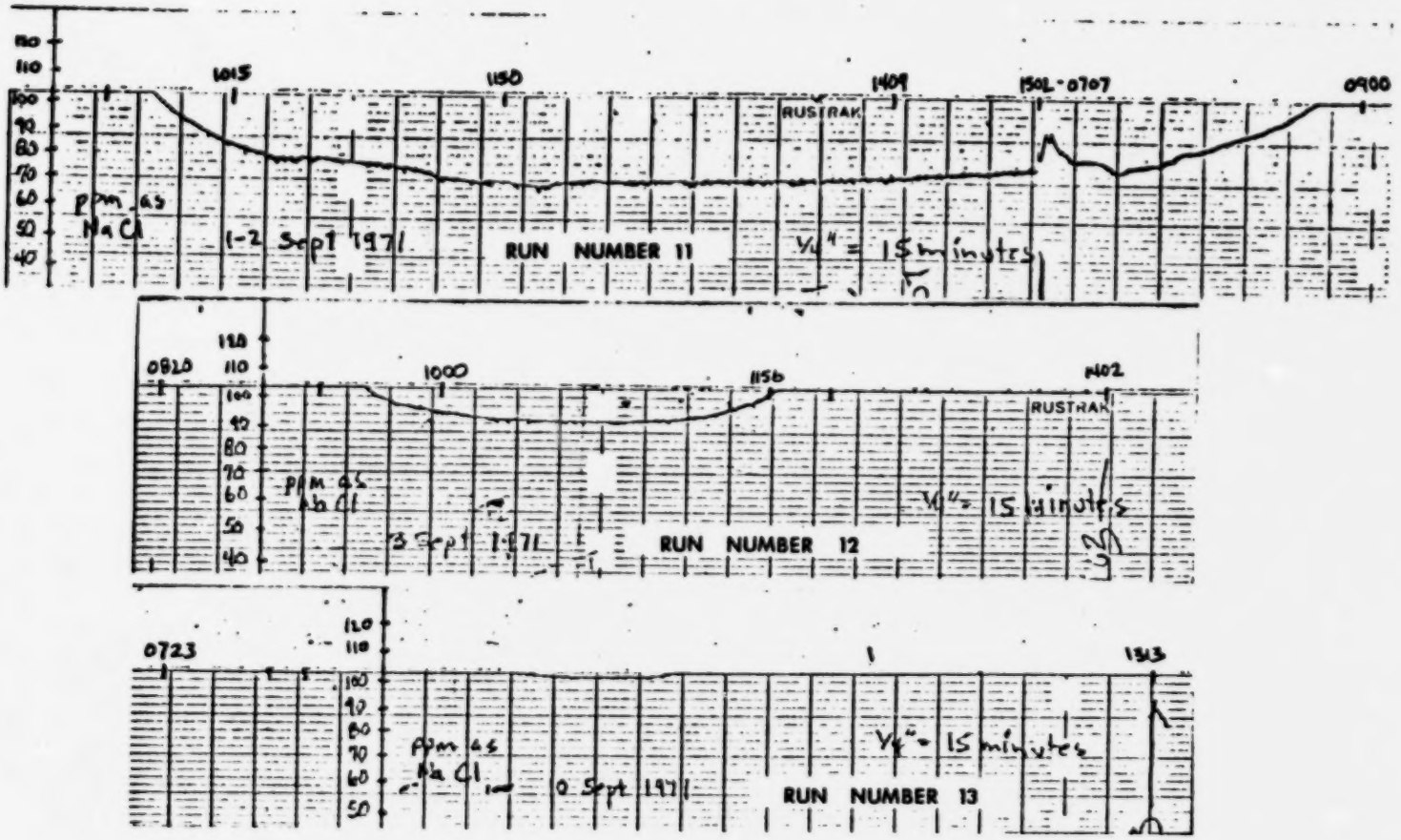

FIGURE 15. PPM AS NaCl OF THE DESAL ION EXCHANGE EFFLUENT FOR RUNS 11, 12, AND 13.

After Run 12, preparations for the next turn around series were made. Problems soon developed when carbonation of column 3 was attempted: the demineralized water pump used for recirculation of the carbonation water began shutting off every 10-20 minutes. The following run, Run 13, gave low ion exchange as shown in the Rustrac recorder chart, Figure 15, and a low 3.9 Kgr/cu ft for lead anion column capacity. Chloride leakage by the lead anion column for Runs 12 and 13 are compared in Figure 16.

Before Run 14, changes were made in the recirculation carbonation system, redirecting the demineralized water back into the demineralized water storage tank instead of sending it directly back to the pump. A back pressure of 12 psig was held while 41.5 pounds of carbon dioxide were injected into column 1. Where Run 13 had a capacity of 3.9 Kgr/cu ft, the subsequent run, Run 14, gave 7.3 Kgr/cu ft with lower chloride leakage (compare Figures 16 and 17).

In the next series, Runs 14 through 19, the higher service flow rate of 1 gal./cu ft/min was used. Carbon dioxide was again injected into the service influent stream. Table 5 indicates the general rise in lead anion column capacity which accompanied the flow rate change.

TABLE 5. CAPACITIES AND SERVICE FLOWS FOR THE THIRD AND FOURTH SERIES.

3rd Series			4th Series		
Run Number	Kgr/cu ft as $CaCO_3$	Service Flow gpm	Run Number	Kgr/cu ft as $CaCO_3$	Service Flow gpm
9	7.3	17	14	7.3	48
10	3.9	18	15	9.5	48
11	7.0	18	16	7.0	42
12	5.4	48	17	9.3	43
			18	3.7	44
			19	6.5	45

Also shown in the table, is the falling trend of capacities as the series progressed. During each series, the lead anion column capacity would decrease for each succeeding run in the same direction. The corresponding rise in chloride leakage is shown in Figure 17. As the capacities decreased, the chloride leakage curves moved up, towards more leakage, and to the left, towards less volume of product water before breakthrough.

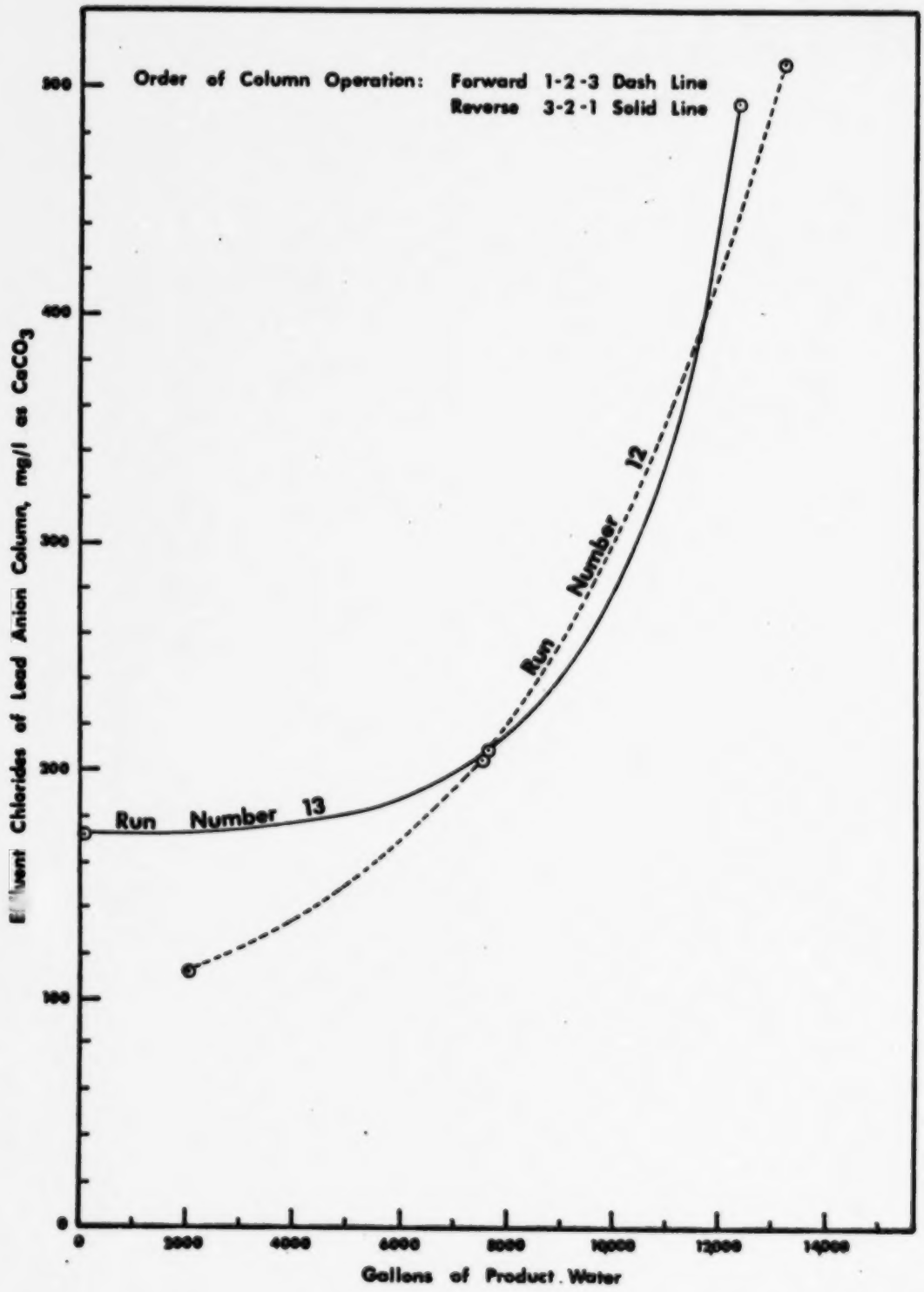

FIGURE 16. INITIAL ANION COLUMN CHLORIDE LEAKAGE FOR RUNS 12 AND 13.

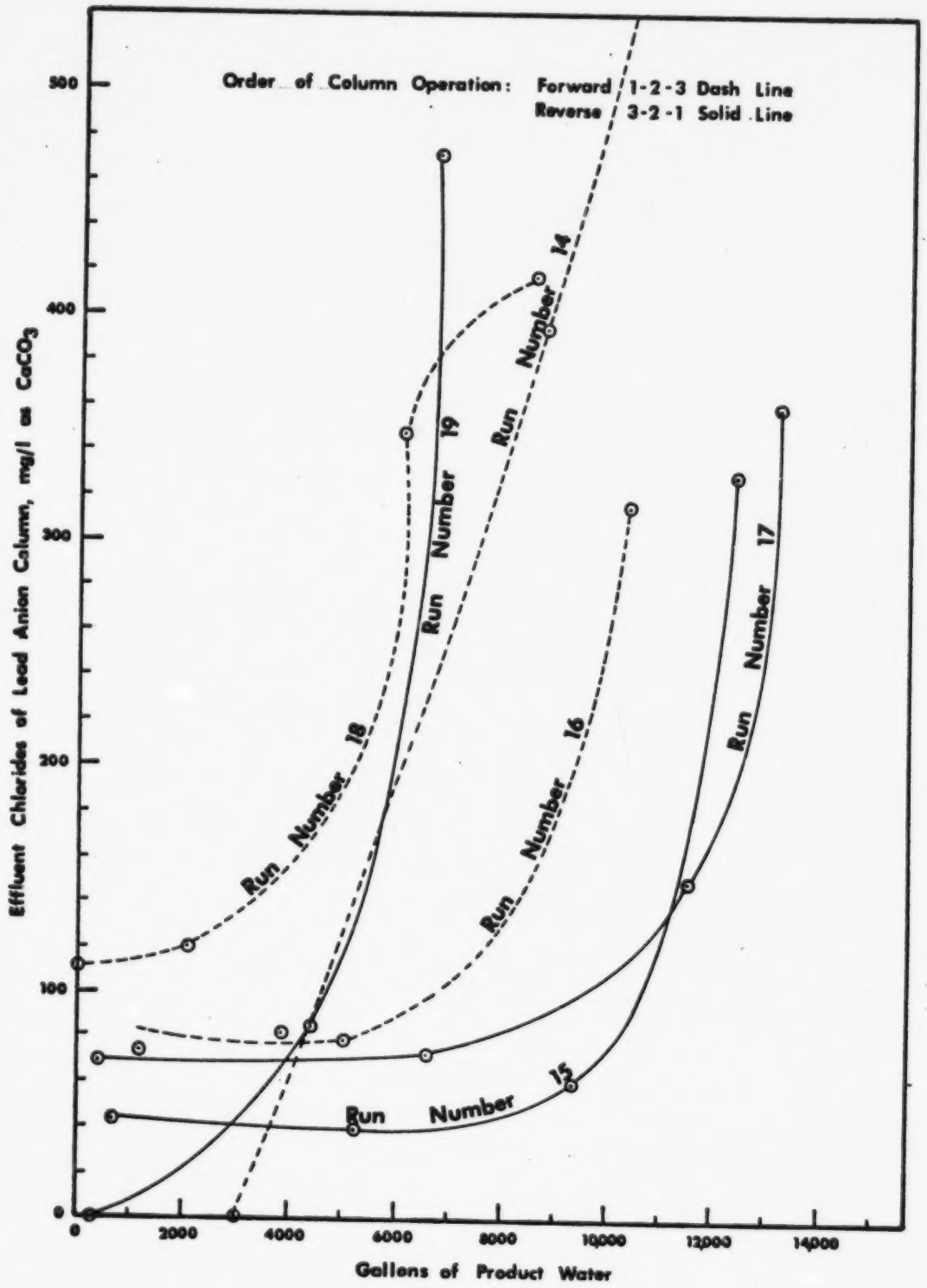

FIGURE 17. FOURTH SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE.

The final series of the project began with the carbonation of anion column 3 using a higher outlet pressure. Because the demineralized water pump was not able to obtain these desired system pressures, the inlet and outlet of the ion exchange feed pump were re-routed so that it could be substituted into the demineralized water stream. A back pressure of 40 psig could then be maintained while carbonating the lead anion column. Column 3 was then carbonated with 50 pounds at carbon dioxide. Also, fresh 26° Be aqua ammonia was used for regeneration of anion Column 1. Run 20 gave the highest capacity of the project, approximately 11 Kgr/cu ft. This was still below the design capacity of 14.5 Kgr/cu ft.

When comparing the actual 11.4 Kgr/cu ft and the 14.5 Kgr/cu ft design capacity of the lead anion column, removal of organic matter by the IRA-68 resin should be considered. From experience earlier in 1971, the lime treated tertiary effluent used for ion exchange feed water, generally ran between 25 and 35 mg/l total COD. If the combined organic and inorganic removals were taken into account, then the 11.4 Kgr/cu ft capacity would have been larger, possibly, equal to or greater than the 14.5 Kgr/cu ft design value.

Runs 21 and 22 both held capacities of 9 and 9.2 Kgr/cu ft with chloride leakages lower than comparable runs in the previous series, compare Figures 17 and 18. The higher capacities and lower chloride leakages followed closely with the increased carbonation pressure. Also, the chloride leakage curves in Figure 18 show more consistency than any of the previous runs.

TURN AROUND SERIES

The project objective was to investigate lead anion column capacity and ion exchange trends in an effort to establish operational parameters which would enable a stable, continuous operation in the design turn-around fashion. A total of 22 runs were made, consisting of 5 turn-around series.

Santee's project personnel collected data during the first series while Arrowhead Puritas controlled run operations. This transition series was used by Arrowhead Puritas for correcting obvious final automatic operational problems and training personnel. Table 6 indicates the percent chloride leakage by the lead anion column at the run shutoff point, and the gallons of product before breakthrough. The breakthrough point was the point at which the bulk of the chloride ions began to leak into the lead anion column effluent, and the chloride leakage curves inflected upwards (refer to Figure 18).

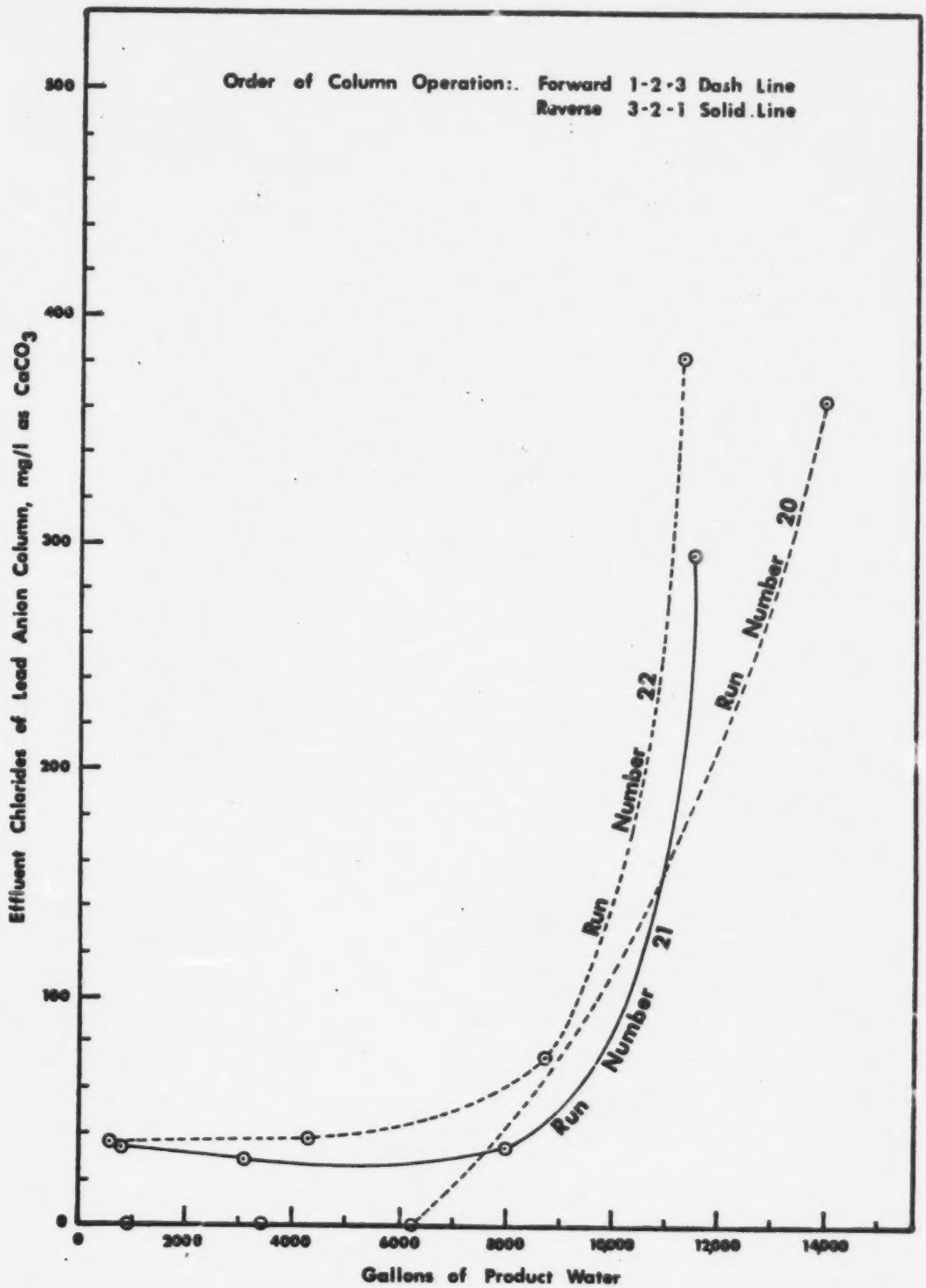

FIGURE 18. FIFTH SERIES INITIAL ANION COLUMN CHLORIDE LEAKAGE.

TABLE 6 CHLORIDE LEAKAGE AT SHUTOFF AND GALLONS OF PRODUCT BEFORE BREAKTHROUGH

Run Number	Percent Chloride Leakage	Gallons of Product Before Breakthrough
1	147	5500
2	31	6000
3	175	9000

For the first three runs, the average percent chloride leakage before the breakthrough point was generally less than 9. The percent leakages were high in Table 6, because the run termination occurred after the breakthrough point. Although for Run 4 no laboratory work was done, it was observed that the Deltec conductivity meter never fell below 80 ppm as NaCl. This indicated a higher product water ion leakage than any of the previous runs.

The second series of turn-around runs, 5 through 8, was the first set of runs controlled by project personnel. Service flows were held close to 19 gpm (0.42 gal./cu ft/min) with product gallonage in the same range as the first series (Table 7). Lead anion column chloride

TABLE 7 CHLORIDE LEAKAGE AT RUN SHUTOFF AND GALLONS OF PRODUCT BEFORE BREAKTHROUGH

Run Number	Percent Chloride Leakage at Shutoff	Gallons of Product Before Breakthrough
5	30	5000
6	31	6000
7	20	7000
8	59	1000

leakage fell between 12 - 20% before breakthrough, as compared with the less than 9% for the first series. Again, as in the first series, the chloride leakages at the run shutoff points were high because the runs were terminated after the breakthrough point.

Early in this series, care was taken to hold the outlet pressure of the final anion column to 30 psig. This lessened the loss of carbon

dioxide through the last column during service. This was the first series for which lead anion column capacities were calculated. (Appendix D, Table 1). They ranged from 5.1 to 4.2 Kgr/cu ft, about one-third of the 14.5 Kgr/cu ft predicted by Rohm and Haas. After Run 8, the turn-around series was stopped and the unit made ready for another carbonation.

In the next set of runs (9 through 12), the service step was extended by raising its termination point. Previously, the service step had been terminated when the unit effluent concentration reached 50 ppm as NaCl. This was changed to the point at which the lead anion column influent and effluent chloride concentrations were equal. This decreased the amount of carbon dioxide left in the lead anion column at run termination. This carbon dioxide which remained in the column was lost when aqua ammonia came in contact with the resin.

The initial run in the third series, (Run 9), after column 3 had been carbonated with 50 pounds of carbon dioxide, produced about 6000 gallons of demineralized water before breakthrough. This was similar to Run 1, where column 3 was carbonated with 236 pounds of carbon dioxide. Initial runs after recarbonation are compared in Figure 19.

Lead anion column chloride leakages before breakthrough ran from zero to 23% for Runs 9, 10, and 11. These leakages were generally higher than the comparable runs in the previous series. Compare Figures 13 and 14. Higher leakages were expected with the higher cut-off point. Run 10 was not representative of the series because of electrical problems in the regeneration and service cycles.

After Run 11, the service flow was changed from 0.5 gal./cu ft/min to 1 gal./cu ft/min. The main reason for the previously low capacities was felt to be the low service flows, and the low operational pressures. Rohm and Haas recommended flows from 1 to 2 gal./cu ft/min for the IRA-68 and IRC-84 resins.

Because of the poor carbonation of Run 13, the method of carbon dioxide injection into the lead anion column was altered. Instead of the recirculating system, the demineralized water was directed through the column then back to the storage tank. 41.5 pounds of carbon dioxide were fed into column 3 while holding the column outlet pressure at 12 psig. After carbonation, the 4th series of turn-around runs (14 through 19) was begun.

Table 8 shows that lead anion column capacities and gallons of demineralized water before breakthrough both increased with the higher flows and carbonation alterations.

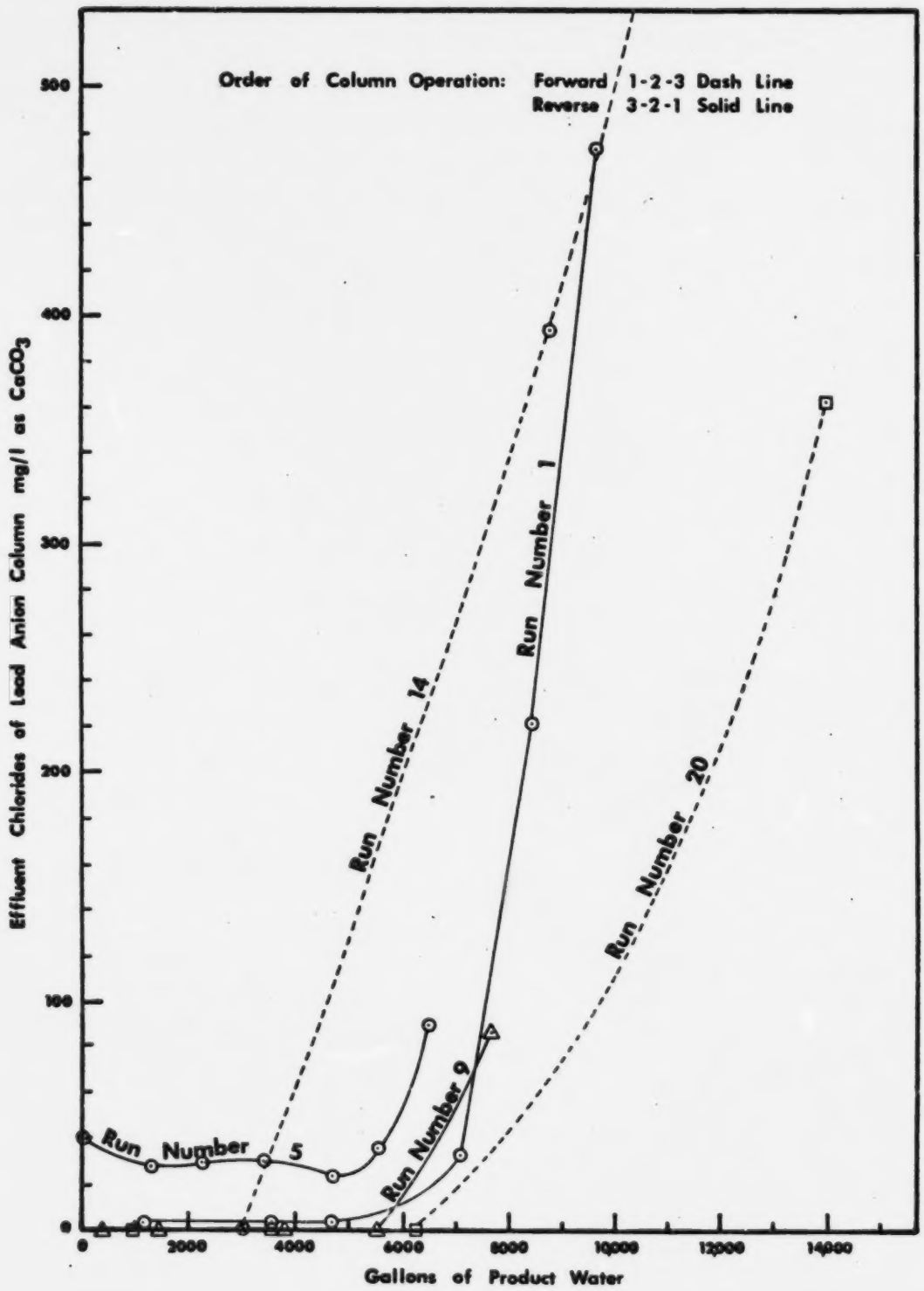

FIGURE 19. INITIAL ANION COLUMN CHLORIDE LEAKAGE FOR THE FIRST RUN OF EACH SERIES.

TABLE 8 LEAD ANION COLUMN CAPACITY AND GALLONS OF DEMINERALIZED WATER BEFORE BREAKTHROUGH

3rd Series				4th Series			
Run Number	Kgr/cu ft	Service Flow gpm	Product Gallons	Run Number	Kgr/cu ft	Service Flow gpm	Product Gallons
9	7.3	17	5500	14	7.3	48	3000
10	3.9	18	3000	15	9.5	48	9000
11	7.0	18	4000	16	7.0	42	7000
12	5.4	48	----	17	9.3	43	9000
				18	3.7	44	3000
				19	6.5	45	1000

Lead anion column chloride leakages ranged from zero to 25% before breakthrough, and were generally higher than the previous series (compare Figures 14 and 17). Note that the previous series had been carbonated at 30 psig outlet pressure, and this one at 12 psig outlet pressure.

Before starting series 5, the ion exchange feed pump was installed in the carbonation system. The flow path was exactly as in the previous carbonation. But this time, instead of holding a column outlet pressure of 12 psig, an outlet pressure of 40 psig was maintained. Also, fresh 26° Be aqua ammonia was used to regenerate the anion columns.

Lead anion column capacities for this series of turn-around runs were higher than those of the last series (Table 9). Along with the higher

TABLE 9 GALLONS OF DEMINERALIZED WATER BEFORE BREAKTHROUGH, AND CAPACITIES FOR SERIES 4 AND 5.

4th Series			5th Series		
Run Number	Kgr/cu ft	Product Gallons	Run Number	Kgr/cu ft	Product Gallons
14	7.3	3000	20	11.4	6000
15	9.5	9000	21	9.7	9000

TABLE 9 GALLONS OF DEMINERALIZED WATER BEFORE BREAKTHROUGH, AND CAPACITIES FOR SERIES 4 AND 5 (continued)

4th Series			5th Series		
Run Number	Kgr/cu ft	Product Gallons	Run Number	Kgr/cu ft	Product Gallons
16	7.0	7000	22	8.6	8500
17	9.3	9000			
18	3.7	3000			
19	6.5	1000			

lead anion column capacities came lower chloride leakages, compare Figures 17 and 18. This was the result of the higher carbonation back pressure before discharging the circulating stream into the demineralized water storage tank. In the 4th series, the back pressure was held at 12 psig, and in the 5th series 40 psig. The higher pressure afforded higher exchange to the bicarbonate form in the lead anion column. Fourth series chloride leakages before breakthrough ranged from zero to 113 ppm as $CaCO_3$, as compared to zero to 30 ppm as $CaCO_3$ during the 5th series.

The higher back pressure also increased the product gallonage. The initial run of the 4th series, Run 14, gave 3000 product gallons before chloride breakthrough, where Run 20, the initial run of the 5th series gave 6200 gallons.

PRODUCT WATER HARDNESS

Leaching of hardness by the final anion column was observed throughout the 22 runs. The hardness was picked-up in the product stream as it passed from the cation column through the final anion column.

The typical pattern of hardness pick-up is given in Table 10. The leakage at the beginning of each run was approximately 50 mg/l as $CaCO_3$; this decreased to zero mg/l as the run progressed. This trend of the leakage indicated the hardness was deposited in the column at sometime in the previous regeneration cycle.

It was felt that, at Santee, there were two main causes of the hardness in the anion columns. First, the collected data showed the presence of hardness in the demineralized water storage tank. Table 11 gives the feed time, amount of gallons, and the hardness range of the product water directed into the storage tank. Some spot checks are also

TABLE 10 RUN 2 FINAL ANION COLUMN HARDNESS LEAKAGE

Product Gallons	Final Anion Column Total Hardness, mg/l as $CaCO_3$	
	Influent	Effluent
----	8.0	62
2400	2.0	22
3600	2.0	26
4800	2.0	6.0
6000	8.0	10
7200	6.0	2.0
8400	12.0	12

included. This hardness could have easily precipitated out when the demineralized water used for the dilution of the aqua ammonia regenerant came in contact with the anion column resin bed.

Hardness precipitation could also have occurred when the dilute aqua ammonia came in contact with the bed volume of feed water left in the anion column after backwash. Since there was no demineralized water rinse of the anion column before the injection of the dilute aqua ammonia, the feed water in the column (containing 250-300 mg/l total hardness as $CaCO_3$), the expended resin, some in the remaining bicarbonate form, and the aqua ammonia were all present at the same time. This was the first suspect for the hardness deposition at Santee.

Another cause must also be considered; the same product water hardness pattern was observed by Epstein, et.al. in Ion Exchange: Field Evaluation of Desal Process (7). They postulated that the hardness deposition occurred during the service cycle. At this time, the lead anion column would have a high concentration of bicarbonate and some amount of carbonate. This carbonate would precipitate out in the resin bed as calcium carbonate, depending on the amount of influent calcium and total dissolved solids. In the reverse cycle, the anion column would then have been in the tail position, where the influent carbonic acid would have dissolved and leached out the calcium carbonate deposit.

This also could have been the cause of the hardness leakage at Santee. It was felt, however, that the first two causes were the immediate suspects, and that they would have to be eliminated before the deposition of calcium carbonate during the service cycle could be considered.

THE CATION COLUMN

For reasons discussed in the introduction, there was limited study of

TABLE 11. TOTAL HARDNESS AND TOTAL GALLONS FED INTO STORAGE TANK.

Run Number	Gallons To Low	mg/l Total Hardness (as $CaCO_3$) Range	Checks	Feed Time Minutes	Total Gallons
1		2		---	---
2		2-22		---	---
3		4		385	4620
4		---		---	---
5	1180	22		335	4030
6		---		316	3790
7		8-20		305	3660
8	1990	20-26		300	3600
9	6310	26-30		248	2980
10	---	10-19		245	2940
11	2890	20-50		307	3660
12	4040	7-25		71	3370
13	---	21-26		70	3330
14	2880	48-68	108	104	4390
15	8340	18-24	84	71	3060
16	3460			73	3190
17	4460	16-20		75	3280
18	---	12-24		98	4020
19	3180	16-38		73	3140
20	3340	62-70	68	58	2820
21	1670	70		50	2200
22	3500	32-42		63	2390

the cation column (IRC-84). Only two runs during the project, Runs 5 and 6, had complete cation-anion balances for IRC-84 capacity calculations.

The capacity of the IRC-84 cation resin was dependent on the influent water temperature, total dissolved solids, and the hardness/alkalinity ratio. The predicted capacities from the above parameters are given in Table 12. As can be seen, the expected IRC-84 capacity was approximately 18.5 Kgr/cu ft.

TABLE 12 INFLUENT PARAMETERS AND EXPECTED CAPACITIES FOR THE IRC-84 RESIN

Run Number	Temperature °F	Total Dissolved Solids mg/l as $CaCO_3$	Total Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	Capacity Kgr/ cu ft
5	approx. 75	820	270	945	18.4
6	approx. 75	790	267	932	18.3

In the Desal plant at Santee, the lead anion column capacity was the limiting factor in the process. The design specifications called for a lead anion column capacity of 14.4 Kgr/cu ft and cation capacity of approximately 18 Kgr/cu ft. Because the highest lead anion column capacity attained during the project was 11.5 Kgr/cu ft, exhaustion of the IRC-84 resin bed was never approached. Actual values for Runs 5 and 6 are summarized in Table 13.

TABLE 13 CAPACITIES FOR RUNS 5 AND 6

Run Number	Lead Anion Column Capacity Kgr/cu ft	Cation Column Capacity Kgr/cu ft
5	5.1	6.2
6	5.1	6.4

SECTION VII

COST ESTIMATES

Ion exchange cost estimates were based upon the Santee plant operation. The values prepared in Table 14 were the results of the projected operation of two complete cycles per 24 hour day. The plant would demineralize activated carbon adsorption effluent and produce 64,370 gallons of 500 mg/l (as $CaCO_3$) total dissolved solids blended effluent. It was assumed that influent water ranged between 700 and 1000 mg/l total dissolved solids, as $CaCO_3$, and that demineralization of the influent water was 86 percent.

It should be emphasized that the removals are based on total dissolved solids (TDS) as the sum of the chloride, sulfate, and alkalinity concentrations, and not the TDS after evaporation. Although the project objective was to investigate the lead anion column performance, and all chemical analysis and data taking were directly related to this end, an effort was made to use the sum of the anion concentrations as the basis for a general cost estimate. The use of this TDS value, instead of the standardly used TDS after evaporation, would tend to make the presented estimate lower than that encountered in actual operation.

Another factor to be considered is the removal of organic matter by the IRA-68. The capacities in the five series were based only on the removal of the anion constituents. If the total organic and inorganic removal were considered, the capacities obtained would have been higher. Also to be considered, is that all project work was done on tertiary effluent. The cost estimate is based on activated carbon adsorption effluent feed water. This feed water would have approximately one-third the organic matter of tertiary effluent. This would allow more of the available capacity to be expended on inorganic rather than organic removal.

Los Angeles construction index values of 133 for October 1968 and 176 for February 1972, were used to update the contractor's bid construction costs. The updated figure was $76,089.75.

Actual regeneration chemical costs were high, at Santee, because of low storage capacity. The storage tanks were limited to 2000 gallons of aqua ammonia and 800 gallons of sulfuric acid. The most convenient shipping quantities from Los Angeles were 3000 gallon lots of sulfuric acid and 5000 gallon lots of aqua ammonia. The prices paid for the smaller quantities of chemicals were $55.35/ton of sulfuric acid and $131.90/ton of aqua ammonia. Storage facilities for 3000 gallons of sulfuric acid and 5000 gallons of aqua ammonia would have brought the cost down to $34.50/ton of sulfuric acid and $89.00/ton of aqua ammonia. Using these figures, the combined shipping and chemical costs for the sulfuric acid could be reduced to $0.021/lb and aqua ammonia to $0.045/lb. These are the values used in Table 14.

TABLE 14. ION EXCHANGE COST ESTIMATE BASED ON 64,370 GALLONS 500 MG/L TDS BLENDED EFFLUENT PER DAY

Operation and Maintenance		Dollars/1000 Gallons of Deionized Water
Labor	5 hrs/day @$5.00/hr	0.311
Maintenance Materials	2% of plant investment/yr	0.005
Power	@$0.009/kWh	0.013
Resin Replacement	cation 10%/yr anion 20%/yr	0.043
Regeneration		
Sulfuric Acid	@$0.021/lb	0.097
Aqua Ammonia	@$0.045/lb	0.192
Carbon Dioxide	@$0.120/lb	0.086
Amortization of Capital $119,460.91 for 20 yrs @ 6%		0.254
Total		1.00

Carbon dioxide costs were partly estimated. Pounds of carbon dioxide used per 1000 gallons of blended effluent were based on figures in the last series of runs (Runs 20-22). It was assumed that the lead anion column would be recarbonated with 50 pounds of carbon dioxide once every 5 runs.

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SECTION VIII

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SECTION IX

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SECTION X

GLOSSARY

Alkalization - The conversion of neutral salts to bicarbonate salts by a weak-base ion exchange resin in the bicarbonate form.

Anion - A negatively charged ion.

Bed Volume - Volume of resin, including the void spaces, contained in the vessel.

Breakthrough - As the ion removal capacity of a resin bed becomes exhausted, the ions being removed by the resin begin to leak into the effluents. This leakage of ion concentration occurs suddenly and increases rapidly.

Capacity - The measure of the adsorption ability of an ion exchange resin. The quantity is expressed in kilograins (Kgr) of substance adsorbed per cubic foot of resin.

Cation - A positively charged ion.

Dealkalization - The conversion of bicarbonate alkalinity to carbonic acid by a weak-acid cation resin in the hydrogen form.

Ion - An atom or group of atoms having either a positive or negative electrical charge.

Lead Anion Column - The first anion column in which the feed water enters.

Leakage - The concentration of ions which pass unadsorbed through the resin, and are found in the column effluent.

Regeneration - The replacement of the ions on the exhausted resin with rejuvenating ions. These desired ions are present in a solution which is passed through the resin bed. The resin exchanges the ions from the exhaustion cycle with the desired ions, regenerating the bed.

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SECTION XI

APPENDICES

		Page
A. Table A-1	Typical Properties of Resins.	57
B. Table B-1 through 21	Chemical Data for Runs 1 through 22.	60
C. Table C-1	Service Flows, Pressures, Gallonage, and Conductance.	91
D. Table D-1 through 18	Pounds of Total Dissolved Solids Removed for Runs 5 through 22.	96
E. Table E-1 and E-2	Cation Column Capacity	115

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Appendix A

TABLE A-1 TYPICAL PROPERTIES OF RESINS.

	Anion Amberlite IRA-68	Cation Amberlite IRC-84
Physical Characteristics:		
Physical Form	Spherical particles, shipped in a completely hydrated condition	Spherical particles, shipped completely hydrated in the hydrogen form
Shipping Wt	46 lbs per cubic foot	47 lbs per cubic foot
Moisture Content	57% - 63%	43% - 50%
Screen Grading	16-50 mesh, wet (U.S. Std. screens)	16-50 mesh, wet (U.S. Std. screens)
Effective Size	0.35 - 0.45 mm	0.38 - 0.46 mm
Uniformity Coefficient	1.70 Maximum	1.80 Maximum
Chemical Characteristics:		
Anion & Cation Exchange Capacity		
Wt Basis	5.6 meq/gm dry	10.5 meq/gm

TABLE A-1 TYPICAL PROPERTIES OF RESINS (continued)

	Anion Amberlite IRA-68	Cation Amberlite IRC-84
Volume Basis	1.6 meq/ml	4.1 meq/ml
Swelling	17%	H Na 65%
Solubility	Insoluble in acids, bases, and all common organic solvents	
Maximum Temperature Limitation	170°F (77°C)	250°F
Regeneration Levels:		
NH_4OH	110% of Theory, as a 4% Solution	
H_2SO_4		110% of Theory, as a 0.5% Solution

Appendix B

TABLE B-1 RUN 1. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	---											
1100	1st Anion Column Effluent		6.6	1152	1.0	1.4							416
	Cation Column Effluent		4.1		0.0	0.0							0.0
	2nd Anion Column Effluent	---											
	Influent	1744	6.5	207	244	344							418
1200	1st Anion Column Effluent		6.7	1159	3.0	4.2							414
	Cation Column Effluent		4.3		0.0	0.0							0.0
	2nd Anion Column Effluent	46	7.3	31	2.0	2.8							2.0
	Influent	1714	6.6	199	244	344							412
1400	1st Anion Column Effluent		6.9	1137	3.0	4.2							410
	Cation Column Effluent		4.2		0.0	0.0							0.0
	2nd Anion Column Effluent	35	7.3	23	2.0	2.8							0.0
	Influent	1642	6.5	182	243	342							374
1500	1st Anion Column Effluent		7.1	1128	2.0	2.8							402
1600	Cation Column Effluent		4.2		0.0	0.0							0.0
	2nd Anion Column Effluent	33	6.0	17	4.0	5.6							0.0

TABLE B-1 RUN 1 (continued). CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
0700	Influent	1749	7.4	203	250	352							416
0800	1st Anion Column Effluent		7.3	1131	24	34							400
	Cation Column Effluent		4.1		0.0	0.0							2.0
	2nd Anion Column Effluent	32	5.2	13	2.0	2.8							2.0
	Influent	1743	7.1	201	251	354							392
0900	1st Anion Column Effluent		7.3	896	159	224							392
	Cation Column Effluent		3.0		0.0	0.0							2.0
	2nd Anion Column Effluent	137	5.3	74	2.0	2.8							0.0
1400	Influent	1673	7.4	195	230	314							390
1500	1st Anion Column Effluent		7.4	528	339	477							386
	Cation Column Effluent		2.7		0.0	0.0							2.0
	2nd Anion Column Effluent	634	6.0	422	0.0	0.0							2.0
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-2 RUN 2. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l Cl	Cl mg/l $CaCO_3$	SO_4 mg/l SO_4	SO_4 mg/l $CaCO_3$	Na mg/l Na	Na mg/l $CaCO_3$	K mg/l K	K mg/l $CaCO_3$	Total Hardness mg/l $CaCO_3$
	Influent	1710	7.1	287	227	320							382
1100	1st Anion Column Effluent		6.8	1145	5.8	8.2							402
	Cation Column Effluent		3.8		5.8	8.2							8.0
	2nd Anion Column Effluent	120	8.3	96	4.9	6.9							62
	Influent	1720	6.9	256	228	321							402
1300	1st Anion Column Effluent		6.7	1130	5.8	8.2							404
	Cation Column Effluent		3.9		7.8	11							2.0
	2nd Anion Column Effluent	60	7.3	41	1.9	2.7							22
	Influent	1700	7.4	260	228	321							404
1400	1st Anion Column Effluent		7.0	1139	6.8	9.6							402
	Cation Column Effluent		4.0		14	20							2.0
	2nd Anion Column Effluent	40	7.4	36	2.9	4.1							26
	Influent	1700	7.0	228	225	317							410
1500	1st Anion Column Effluent		7.1	1124	7.8	11							394
	Cation Column Effluent		4.0		9.7	14							2.0
	2nd Anion Column Effluent	40	7.0	37	1.9	2.7							6.0

TABLE B-2 RUN 2 (continued). CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1680	6.5	204	238	335							402
1600	1st Anion Column Effluent		7.2	111	4.8	6.8							402
	Cation Column Effluent		3.8		11	16							8.0
	2nd Anion Column Effluent	50	6.6	24	14	20							10
	Influent	1680	6.3	181	227	320							392
1700	1st Anion Column Effluent		7.3	1067	33	47							392
	Cation Column Effluent		3.5		33	47							6.0
	2nd Anion Column Effluent	40	6.2	25	5.8	8.2							2.0
	Influent	1670	6.0	166	234	333							384
1800	1st Anion Column Effluent		7.2	995	73	103							380
	Cation Column Effluent		3.1		50	71							12
	2nd Anion Column Effluent	75	6.1	41	5.8	8.2							12
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-3 RUN 3. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1250	7.3		230	324							
0900	1st Anion Column Effluent		6.9		6.9	9.7							
	Cation Column Effluent		4.2										
	2nd Anion Column Effluent	120	8.4		2.9	4.1							
	Influent	1285	7.2		232	317							
1000	1st Anion Column Effluent		7.1		7.8	11							
	Cation Column Effluent		4.4		9.8	14							
	2nd Anion Column Effluent	102	8.4		1.0	1.4							
	Influent	1300	7.2		232	317							
1100	1st Anion Column Effluent		7.0		8.8	12							
	Cation Column Effluent		4.4										
	2nd Anion Column Effluent	80	8.3		0.0	0.0							
	Influent	1250	7.1		229	322							
1300	1st Anion Column Effluent		7.0		7.8	11							
	Cation Column Effluent		4.4										
	2nd Anion Column Effluent	65	8.2		0.0	0.0							

TABLE B-3 RUN 3 (continued). CHEMICAL DATA

Time	3-2-1 Operation Mode	μmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1150	7.1		228	321							
1400	1st Anion Column Effluent		6.9		11	16							
	Cation Column Effluent		4.4										
	2nd Anion Column Effluent	45	8.1		0.0	0.0							
	Influent	950	6.9		226	318							
1500	1st Anion Column Effluent		7.1		8.8	12							
	Cation Column Effluent		4.3										
	2nd Anion Column Effluent	55	8.1		0.0	0.0							
	Influent	1400	7.0		225	317							
1600	1st Anion Column Effluent		7.0		8.8	12							
	Cation Column Effluent		4.3										
	2nd Anion Column Effluent	55	8.0		0.0	0.0							
	Influent	1250	7.1		224	315							
1700	1st Anion Column Effluent		6.9		7.8	11							
	Cation Column Effluent		4.3										
	2nd Anion Column Effluent	32	8.0		0.0	0.0							

TABLE B-3 RUN 3 (continued). CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l Cl	Cl mg/l $CaCO_3$	SO_4 mg/l SO_4	SO_4 mg/l $CaCO_3$	Na mg/l Na	Na mg/l $CaCO_3$	K mg/l K	K mg/l $CaCO_3$	Total Hardness mg/l $CaCO_3$
	INFLUENT	1150	7.8		229	322							
1800	1ST Anion Column Effluent		7.4		47	66							
	Cation Column Effluent		4.2										
	2nd Anion Column Effluent	55	8.1		0.0	0.0							
	Influent	1150	7.6		234	329							
1915	1st Anion Column Effluent		7.5		411	577							
	Cation Column Effluent		3.0										
	2nd Anion Column Effluent	650	8.4		9.8	14							
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

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TABLE B-4 RUN 5. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1736	6.2	131	176	248	370	386	250	546	22	29	270
0840	1st Anion Column Effluent		6.8	939	28	39	4.5	4.7					
	Cation Column Effluent		3.5						18	37	1.1	1.4	10
	2nd Anion Column Effluent	201	8.4	116	0.0	0.0	3.0	3.1					
	Influent	1609	6.2	150	176	248	380	396	245	534	22	28	266
0950	1st Anion Column Effluent		6.9	955	22	31	4.5	4.7					
	Cation Column Effluent		3.6						18	40	1.1	1.4	20
	2nd Anion Column Effluent	120	7.9	61	0.0	0.0	3.0	3.1					
	Influent	1671	6.3	162	176	248	370	386	235	513	20	26	268
1038	1st Anion Column Effluent		6.9	958	21	30	3.0	3.1					
	Cation Column Effluent		3.7						17	37	1.0	1.3	0.0
	2nd Anion Column Effluent	110	7.8	54	0.0	0.0	3.0	3.1					
	Influent	1626	6.2	160	168	237	365	380	235	513	20	26	270
1137	1st Anion Column Effluent		7.0	953	18	25	0.0	0.0					
	Cation Column Effluent		3.7						15	33	1.0	1.3	0.0
	2nd Anion Column Effluent	99	7.5	41	0.0	0.0	0.0	0.0					

TABLE B-4 RUN 5 (continued). CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1444	6.1	160	148	208	340	354	235	513	20	26	270
1240	1st Anion Column Effluent		6.8	945	17	23	3.0	3.1					
	Cation Column Effluent		3.8						16	35	0.7	0.9	0.0
	2nd Anion Column Effluent	92	7.4	43	0.0	0.0	9.0	9.4					
	Influent	1380	5.9	147	168	237	360	375	230	503	20	26	270
1332	1st Anion Column Effluent		6.9	942	26	36	3.0	3.1					
	Cation Column Effluent		3.8						18	37	0.8	1.0	0.0
	2nd Anion Column Effluent	96	7.3	43	0.0	0.0	10	10					
	Influent	1391	7.8	157	176	248	370	385	235	513	20	26	292
1354	1st Anion Column Effluent		6.9	906	36	51	3.0	3.1					
	Cation Column Effluent		3.6						22	49	0.9	1.2	4.0
	2nd Anion Column Effluent	102	7.4	53	0.0	0.0	10	10					
	Influent	1736	8.3	149	216	304	370	386	235	513	20	26	286
1430	1st Anion Column Effluent		7.2	834	64	90	3.0	3.1					
	Cation Column Effluent		3.6						22	49	1.6	2.0	6.0
	2nd Anion Column Effluent	201	7.9	67	0.0	0.0	10	10					

TABLE B-5 RUN 6. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1610	6.4	166	168	237	425	442	235	512	22	28	272
1001	1st Anion Column Effluent		6.7	953	20	28	6.0	6.2					
	Cation Column Effluent		3.7						19	42	1.2	1.5	4.0
	2nd Anion Column Effluent	175	8.1	92	0.0	0.0	5.5	5.7					
	Influent	1573	6.3	166	136	192	400	416	225	491	21	27	274
1048	1st Anion Column Effluent		6.9	953	18	25	3.5	3.6					
	Cation Column Effluent		3.6						18	40	1.1	1.4	0.0
	2nd Anion Column Effluent	173	8.2	99	0.0	0.0	6.0	6.2					
	Influent	1582	6.0	157	140	197	390	406	225	491	21	27	262
1151	1st Anion Column Effluent		6.8	929	19	27	6.0	6.2					
	Cation Column Effluent		3.5						19	42	1.1	1.4	0.0
	2nd Anion Column Effluent	171	8.1	99	0.0	0.0	7.0	7.3					
	Influent	1656	6.1	151	128	181	350	364	235	512	20	26	262
1251	1st Anion Column Effluent		6.8	937	19	26	6.5	6.8					
	Cation Column Effluent		3.7						19	42	1.1	1.4	4.0
	2nd Anion Column Effluent	173	8.1	96	0.0	0.0	7.0	7.3					

TABLE B-5 RUN 6 (continued). CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l Cl	Cl mg/l $CaCO_3$	SO_4 mg/l SO_4	SO_4 mg/l $CaCO_3$	Na mg/l Na	Na mg/l $CaCO_3$	K mg/l K	K mg/l $CaCO_3$	Total Hardness mg/l $CaCO_3$
	Influent	1638	6.0	142	124	175	320	332	225	491	20	26	272
1351	1st Anion Column Effluent		6.8	912	17	23	4.5	4.7					
	Cation Column Effluent		3.6						18	40	1.1	1.4	2.0
	2nd Anion Column Effluent	172	7.9	100	0.0	0.0	4.5	4.7					
	Influent	1564	6.3	137	156	220	340	354	225	491	20	26	260
1456	1st Anion Column Effluent		6.9	906	32	45	3.0	3.1					
	Cation Column Effluent		3.7						19	42	1.0	1.3	0.0
	2nd Anion Column Effluent	171	8.1	100	0.0	0.0	5.0	5.2					
	Influent	1472	6.2	128	156	220	340	354	225	491	20	26	260
1520	1st Anion Column Effluent		6.9	893	48	68	3.5	3.6					
	Cation Column Effluent		3.8						23	51	1.2	1.5	0.0
	2nd Anion Column Effluent	167	8.1	99	0.0	0.0	5.0	5.2					
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-6 RUN 7. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
0820	Influent	1755	6.8	312	160	226	420	438					358
	1st Anion Column Effluent		7.4	1035	32	45	6.5	6.8					
	Cation Column Effluent		3.7										2.0
	2nd Anion Column Effluent	351	8.7										62
0854	Influent	1814	6.9	293	148	209	420	438					376
	1st Anion Column Effluent		7.5	1014	25	35	4.0	4.2					
	Cation Column Effluent		3.7										2.0
	2nd Anion Column Effluent	191	8.6										34
0929	Influent	1862	6.6	323	136	192	420	437					374
	1st Anion Column Effluent		7.6	1019	25	35	6.0	6.3					
	Cation Column Effluent		3.8										4.0
	2nd Anion Column Effluent	180	8.4										28
1100	Influent	1833	6.5	305	136	192	400	416					382
	1st Anion Column Effluent		7.5	815	24	34	6.0	6.3					
	Cation Column Effluent		3.8										2.0
	2nd Anion Column Effluent	144	8.4										21

TABLE B-6 RUN 7 (continued). CHEMICAL DATA

Time	3-2-1 Operation Mode	μmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1832	6.5	323	152	214	410	426					380
1322	1st Anion Column Effluent		7.4	997	24	34	2.0	2.1					
	Cation Column Effluent		3.4										12
	2nd Anion Column Effluent	186	8.4										10
	Influent	1833	6.5	304	148	210	340	354					386
1434	1st Anion Column Effluent		7.5	650	30	42	4.5	4.7					
	Cation Column Effluent		3.4										4.0
	2nd Anion Column Effluent	359	8.4										8.0
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-7 RUN 8. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1794	7.1	197	192	271	400	417					280
0837	1st Anion Column Effluent		7.3	900	46	65	5.5	5.7					
	Cation Column Effluent		3.4										2.0
	2nd Anion Column Effluent	270	8.6										42
	Influent	1708	7.1	200	180	254	340	354					278
0920	1st Anion Column Effluent		7.3	906	45	64	6.0	6.3					
	Cation Column Effluent		3.6										4.0
	2nd Anion Column Effluent	241	8.8										34
	Influent	1750	6.0	192	160	226	340	354					270
1044	1st Anion Column Effluent		7.2	848	60	85	5.5	5.7					
	Cation Column Effluent		3.4										2.0
	2nd Anion Column Effluent	232	8.6										26
	Influent	1697	6.0	187	160	226	330	343					272
1147	1st Anion Column Effluent		7.3	755	74	104	5.5	5.7					
	Cation Column Effluent		3.7										6.0
	2nd Anion Column Effluent	239	8.6										22

TABLE B-7 RUN 8 (continued). CHEMICAL DATA

Time	1-2-3 Operation Mode	μmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1673	6.1	182	160	226	340	354					230
1319	1st Anion Column Effluent		7.3	601	94	133	5.5	5.7					
	Cation Column Effluent		3.6										2.0
	2nd Anion Column Effluent	247	8.8										20
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-8 RUN 9. CHEMICAL DATA

Time	3-2-1 Operation Mode	μmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1580	5.9	83	172	243	395	411					168
0940	1st Anion Column Effluent		6.9	903	0.0	0.0	11	11					
	Cation Column Effluent		3.6										14
	2nd Anion Column Effluent	176	8.6										60
	Influent	1549	5.9	87	170	240	410	426					180
1044	1st Anion Column Effluent		6.8	902	0.0	0.0	8.0	8.3					
	Cation Column Effluent		3.6										4.0
	2nd Anion Column Effluent	123	8.1										46
	Influent	1547	5.7	75	156	220	388	404					174
1308	1st Anion Column Effluent		6.4	865	0.0	0.0	6.0	6.3					
	Cation Column Effluent		3.8										0.0
	2nd Anion Column Effluent	91	7.9										30
	Influent	1585	5.6	102	148	209	340	354					214
1452	1st Anion Column Effluent		6.5	856	0.0	0.0	0.0	0.0					
	Cation Column Effluent		3.4										0.0
	2nd Anion Column Effluent	86	7.8										26

TABLE B-8 RUN 9 (continued). CHEMICAL DATA

Time	3-2-1 Operation Mode	μmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1633	6.5	204	204	288	362	377					274
0726	1st Anion Column Effluent		7.2	832	60	85	0.0	0.0					
	Cation Column Effluent		3.5										1.0
	2nd Anion Column Effluent	146	8.7										16
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-9 RUN 10. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1650	7.2	234	248	350	415	432					330
0800	1st Anion Column Effluent		7.0	1095	21	30	0.0	0.0					
	Cation Column Effluent		3.5										0.0
	2nd Anion Column Effluent	140	8.2										19
	Influent	1706	6.1	215	236	333	285	296					298
0939	1st Anion Column Effluent		7.3	1132	21	30	5.0	5.2					
	Cation Column Effluent		3.8										0.0
	2nd Anion Column Effluent	102	8.4										20
	Influent	1566	6.0	202	253	357	290	302					298
1200	1st Anion Column Effluent		7.3	662	216	305	8.8	9.2					
	Cation Column Effluent		3.1										4.0
	2nd Anion Column Effluent	258	8.7										10
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-10 RUN 11. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1667	6.6	264	217	306	335	348					252
1015	1st Anion Column Effluent		7.3	1012	49	69	3.0	3.1					
	Cation Column Effluent		3.4										2.0
	2nd Anion Column Effluent	244	8.9										60
	Influent	1628	6.1	129	218	307	320	333					252
1150	1st Anion Column Effluent		7.2	902	33	47	3.0	3.1					
	Cation Column Effluent		3.4										4.0
	2nd Anion Column Effluent	199	8.7										50
	Influent	1601	5.9	105	214	302	335	348					240.
1409	1st Anion Column Effluent		7.0	959	62	87	7.5	7.8					
	Cation Column Effluent		3.3										2.0
	2nd Anion Column Effluent	178	8.4										20
	Influent	1650	6.0	76	230	324	335	348					217
0900	1st Anion Column Effluent		7.4	531	247	348	28	29					
	Cation Column Effluent		3.1										13
	2nd Anion Column Effluent	392	8.9										16

TABLE B-11 RUN 12. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1620	8.0	301	234	330	330	343					290
1000	1st Anion Column Effluent		7.4	811	80	113	3.0	3.1					
	Cation Column Effluent		3.0										0.20
	2nd Anion Column Effluent	295	8.4										34
	Influent	1687	6.3	155	230	324	320	333					296
1156	1st Anion Column Effluent		7.3	668	147	207	3.0	3.1					
	Cation Column Effluent		3.3										1.0
	2nd Anion Column Effluent	297	8.6										25
	Influent	1660	7.5	155	231	326	360	374					286
1402	1st Anion Column Effluent		7.2	297	364	513	6.0	6.2					
	Cation Column Effluent		2.7										7.0
	2nd Anion Column Effluent	870	8.5										7.0
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-12 RUN 13. CHEMICAL DATA

Time	3-2-1 Operation Mode	μmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1525	6.8	165	232	327	340	363					298
0844	1st Anion Column Effluent		6.9	790	124	175	3.5	3.6					
	Cation Column Effluent		3.3										5.0
	2nd Anion Column Effluent	373	8.9										37
	Influent	1641	6.6	159	223	314	335	348					318
1016	1st Anion Column Effluent		7.0	768	128	180	3.5	3.6					
	Cation Column Effluent		3.2										2.0
	2nd Anion Column Effluent	346	8.5										25
	Influent	1480	6.7	150	220	310	345	358					296
1126	1st Anion Column Effluent		7.2	700	150	211	3.0	3.1					
	Cation Column Effluent		3.2										7.0
	2nd Anion Column Effluent	380	8.6										21
	Influent	1600	6.6	146	217	306	345	358					292
1308	1st Anion Column Effluent		7.3	384	352	495	3.0	3.1					
	Cation Column Effluent		3.1										3.0
	2nd Anion Column Effluent	755	8.8										26

TABLE B-13 RUN 14. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1658	6.8	167	219	309	330	343					296
1016	1st Anion Column Effluent		6.7	1008	0.0	0.0	3.0	3.1					
	Cation Column Effluent		4.0										0.0
	2nd Anion Column Effluent	230	8.5										78
	Influent	1600	6.5	171	214	302	335	348					300
1127	1st Anion Column Effluent		6.8	1000	0.0	0.0	3.0	3.1					
	Cation Column Effluent		3.8										0.0
	2nd Anion Column Effluent	196	8.2										68
	Influent	1499	6.4	167	207	292	370	385					308
1344	1st Anion Column Effluent		7.3	521	281	396	4.0	4.2					
	Cation Column Effluent		2.7										14
	2nd Anion Column Effluent	339	8.0										48
	Influent	1499	6.3	172	211	298	330	343					304
1420	1st Anion Column Effluent		7.4	288	416	587	3.0	3.1					
	Cation Column Effluent		3.2										12
	2nd Anion Column Effluent	715	7.3										34

TABLE B-14 RUN 15. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1596	6.2	128	227	320	320	333					300
0807	1st Anion Column Effluent		6.6	837	31	44	0.0	0.0					
	Cation Column Effluent		3.0										0.0
	2nd Anion Column Effluent	244	8.5										56
	Influent	1653	5.9	189	222	313	335	348					297
0954	1st Anion Column Effluent		6.4	784	30	42	3.5	3.6					
	Cation Column Effluent		3.4										0.0
	2nd Anion Column Effluent	156	8.3										24
	Influent	1597	5.8	98	220	310	335	348					278
1131	1st Anion Column Effluent		6.4	761	43	61	3.5	3.6					
	Cation Column Effluent		3.4										0.0
	2nd Anion Column Effluent	129	8.3										18
	Influent	1607	5.6	90	212	299	335	348					278
1240	1st Anion Column Effluent		7.1	485	235	331	3.0	3.1					
	Cation Column Effluent		3.0										8.0
	2nd Anion Column Effluent	313	8.5										18

TABLE B-15 RUN 16. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1627	6.1	103	223	314	335	348					276
0946	1st Anion Column Effluent		6.7	829	53	75	3.5	3.6					
	Cation Column Effluent		3.3										0.0
	2nd Anion Column Effluent	276	8.4										54
	Influent	1632	6.3	104	224	316	330	343					274
1045	1st Anion Column Effluent		7.0	985	59	83	3.5	3.6					
	Cation Column Effluent		3.2										2.0
	2nd Anion Column Effluent	214	8.3										28
	Influent	1570	6.0	97	222	313	320	333					282
1158	1st Anion Column Effluent		6.9	826	57	80	3.5	3.6					
	Cation Column Effluent		3.3										2.0
	2nd Anion Column Effluent	200	8.4										28
	Influent	1580	6.2	109	218	307	320	333					278
1313	1st Anion Column Effluent		7.3	560	225	317	3.5	3.6					
	Cation Column Effluent		2.9										6.0
	2nd Anion Column Effluent	349	8.4										20

TABLE B-16 RUN 17. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1620	6.7	94	221	312	320	332					230
0919	1st Anion Column Effluent		7.8	822	50	71	3.5	3.6					
	Cation Column Effluent		4.0										0.0
	2nd Anion Column Effluent	260	9.4										42
	Influent	1580	6.5	87	217	306	345	358					232
1131	1st Anion Column Effluent		7.7	831	52	73	3.0	3.1					
	Cation Column Effluent		3.9										0.0
	2nd Anion Column Effluent	198	9.0										20
	Influent	1570	6.6	79	213	300	330	343					234
1324	1st Anion Column Effluent		7.8	742	107	151	4.0	4.2					
	Cation Column Effluent		3.7										2.0
	2nd Anion Column Effluent	213	8.9										16
	Influent	1550	6.6	77	218	307	335	348					238
1403	1st Anion Column Effluent		7.6	479	257	362	4.0	4.2					
	Cation Column Effluent		3.4										7.0
	2nd Anion Column Effluent	390	9.1										14

TABLE B-17 RUN 18. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l Cl	Cl mg/l $CaCO_3$	SO_4 mg/l SO_4	SO_4 mg/l $CaCO_3$	Na mg/l Na	Na mg/l $CaCO_3$	K mg/l K	K mg/l $CaCO_3$	Total Hardness mg/l $CaCO_3$
	Influent	1667	6.4	161	229	323	356	370					313
1040	1st Anion Column Effluent		7.3	793	80	113	3.5	3.6					
	Cation Column Effluent		3.4										2.0
	2nd Anion Column Effluent	254	8.9										31
	Influent	1680	6.6	166	222	313	335	348					318
1130	1st Anion Column Effluent		7.4	780	85	120	3.5	3.6					
	Cation Column Effluent		3.6										0.0
	2nd Anion Column Effluent	255	9.0										24
	Influent	1670	6.6	164	221	312	350	364					322
1308	1st Anion Column Effluent		7.5	482	248	350	4.0	4.2					
	Cation Column Effluent		3.2										6.0
	2nd Anion Column Effluent	422	9.0										14
	Influent	1648	6.6	167	216	305	350	364					328
1406	1st Anion Column Effluent		7.5	363	297	419	3.5	3.6					
	Cation Column Effluent		3.1										8.0
	2nd Anion Column Effluent	683	9.0										12

TABLE B-18 RUN 19. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1530	5.7	52	214	301	335	348					218
1455	1st Anion Column Effluent		8.6	636	1.0	1.4	3.5	3.6					
	Cation Column Effluent		5.0										0.0
	2nd Anion Column Effluent	170	9.3										44
	Influent	1717	6.6	221	249	351	335	348					300
0847	1st Anion Column Effluent		9.0	703	60	85	3.0	3.1					
	Cation Column Effluent		4.0										0.0
	2nd Anion Column Effluent	149	8.9										44
	Influent	1810	6.7	213	242	341	325	338					294
0940	1st Anion Column Effluent		8.6	308	334	470	3.0	3.1					
	Cation Column Effluent		3.2										18
	2nd Anion Column Effluent	419	9.3										16
	Influent												
	1st Anion Column Effluent												
	Cation Column Effluent												
	2nd Anion Column Effluent												

TABLE B-19 RUN 20. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1789	6.4	196	237	334	360	374					318
1006	1st Anion Column Effluent		7.1	935	0.0	0.0	3.5	3.6					
	Cation Column Effluent		4.8										0.0
	2nd Anion Column Effluent	177	9.2										62
	Influent	1758	6.5	194	209	294	390	406					322
1057	1st Anion Column Effluent		7.1	1014	0.0	0.0	0.0	0.0					
	Cation Column Effluent		4.8										0.0
	2nd Anion Column Effluent	166	9.0										62
	Influent	1633	6.6	191	229	322	360	374					326
1155	1st Anion Column Effluent		7.4	1009	0.0	0.0	3.5	3.6					
	Cation Column Effluent		4.8										0.0
	2nd Anion Column Effluent	156	9.0										70
	Influent	1706	6.7	160	212	298	330	343					312
1455	1st Anion Column Effluent		7.5	551	257	362	3.0	3.1					
	Cation Column Effluent		3.2										10
	2nd Anion Column Effluent	468	9.0										54

TABLE B-20 RUN 21. CHEMICAL DATA

Time	3-2-1 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
	Influent	1642	6.7	152	216	305	365	379					292
1043	1st Anion Column Effluent		7.0	904	25	35	4.0	4.2					
	Cation Column Effluent		3.3										0.0
	2nd Anion Column Effluent	196	8.6										50
	Influent	1683	6.8	133	214	302	330	343					284
1135	1st Anion Column Effluent		7.2	904	22	31	3.0	3.1					
	Cation Column Effluent		3.3										0.0
	2nd Anion Column Effluent	187	8.3										52
	Influent	1490	6.4	141	214	302	380	395					284
1328	1st Anion Column Effluent		7.2	913	26	37	4.0	4.2					
	Cation Column Effluent		3.9										0.0
	2nd Anion Column Effluent	201	8.5										70
	Influent	1654	6.3	127	212	298	335	348					290
1450	1st Anion Column Effluent		7.2	733	211	297	0.0	0.0					
	Cation Column Effluent		3.2										8.0
	2nd Anion Column Effluent	300	8.2										74

TABLE B-21 RUN 22. CHEMICAL DATA

Time	1-2-3 Operation Mode	µmhos/cm @25°C	pH	HCO_3 mg/l $CaCO_3$	Cl mg/l		SO_4 mg/l		Na mg/l		K mg/l		Total Hardness mg/l $CaCO_3$
					Cl	$CaCO_3$	SO_4	$CaCO_3$	Na	$CaCO_3$	K	$CaCO_3$	
1447	Influent	1570	6.1	55	213	287	330	343					250
	1st Anion Column Effluent		7.4	815	26	37	3.0	3.1					
	Cation Column Effluent		3.8										0.0
	2nd Anion Column Effluent	177	9.0										38
0758	Influent	1642	6.0	47	238	335	350	364					254
	1st Anion Column Effluent		7.3	861	28	39	3.5	3.6					
	Cation Column Effluent		3.7										0.0
	2nd Anion Column Effluent	146	8.8										32
0956	Influent	1600	6.1	60	230	324	320	332					250
	1st Anion Column Effluent		7.4	836	52	73	2.0	2.1					
	Cation Column Effluent		3.8										2.0
	2nd Anion Column Effluent	171	8.6										42
1104	Influent	1622	6.1	45	226	319	350	364					242
	1st Anion Column Effluent		7.5	453	270	380	3.0	3.1					
	Cation Column Effluent		3.2										20
	2nd Anion Column Effluent	365	9.0										22

Appendix C

TABLE C-1 SERVICE DATA

Run Number	Time	Product TDS ppm as NaCl	Service Flow Rate gpm	Pressure psig Influent	Pressure psig Effluent	Total Gallons
	1100		20	40	10	
	1200		20	40	10	1200
	1400	no	20	40	10	3600
1	1500	data	20	40	10	4800
	0800		20	40	10	7200
	0900		20	40	10	8400
	1500		20	40	10	9600
	1100		20	40	10	
	1300		20	40	10	2400
	1400	no	20	40	10	3600
2	1500	data	20	40	10	4800
	1600		20	40	10	6000
	1700		20	40	10	7200
	1800		20	40	10	8400
	0900	---	21	45	40	
	1000	36	21	45	40	1260
	1100	37	21	45	40	2520
	1300	21	21	45	40	5040
3	1400	18	21	45	40	6300
	1500	19.5	21	45	40	no flow
	1600	18.5	21	42	39.5	7670
	1700	17.5	23	42	25	9050
	1800	---	23	42	25	10,430
	1915	---	23	42	25	11,930
4						
no data						

TABLE C-1(continued). SERVICE DATA

Run Number	Time	ppm as NaCl	Service Flow Rate gpm	Pressure psig Influent	Pressure psig Effluent	Total Gallons
	0840	95	21	40	9	
	0950	42	19	40	18	1330
	1038	38	19	42	19	2240
5	1137	33	19	42	19.5	3360
	1240	29	19	42	20	4560
	1332	31	19	42	29	5550
	1354	34	18	43	28	5970
	1430	50	18	43	28	6650
	1001	65	19	44	34	1100
	1048	67	18	44	37	1990
	1151	66	19	44	36	3200
6	1251	65	19	44	36	4340
	1351	65	18	44	36	5480
	1456	66	18	44	36	6710
	1520	64	18	44	34	7160
	0820		19	41	12	
	0854		19	44	37	610
7	0929		19	44	37	1240
	1100	no	19	44	38	2880
	1322	data	19	44	38	5440
	1434		19	44	38	6740
	0837	100	21	42	18	170
	0920	90	21	42	18	1070
8	1044	89	18	44	43	2500
	1147	90	18	44	43	3570
	1419	100	18	44	43	5130
	0940	70	18	42	30	340
	1044	45	18	43	32	1430
9	1308	35.5	19	43	32	3870
	1452	34	19	43	32	5640
	0840	54	19	42	30	7780

TABLE C-1 (continued). SERVICE DATA

Number	Time	Product TDS ppm as NaCl	Service Flow Rate gpm	Pressure psig Influent	Pressure psig Effluent	Total Gallons
10	0800	54	20	44	30	560
	0939	39	19	45	29	2340
	1200	90	19	44	30	5240
11	1015	85	20	43	32	812
	1150	69	19	43	32	2520
	1409	72	19	43	32	5020
	0900	120	19	42	29	8020
12	1000	100	47.5	69	30	7560
	1156	100	47.5	69	30	8560
	1402	120+	47.5	69	30	11,700
13	0844	120	47.5	66	30	
	1016	110	47.5	66	30	4360
	1126	119	47.5	66	30	7680
	1308	120+	47.5	67	31	12,420
14	1016	90	42.3	72	28	720
	1127	69	42.3	73	30	3720
	1344	118	42.3	74	31	9500
	1420	120+	42.3	74	31	11,020
15	0807	100	43	66	29	650
	0954	54	43	70	30	5240
	1131	49	43	71	30	9400
	1240	102	43	71	30	12,450
16	0946	96	43.7	70	29	960
	1045	76	43.7	70	30	3540
	1158	77	43.7	71	30	6730
	1313	112	43.7	70	30	10,010

TABLE C-1(continued). SERVICE DATA

Number	Time	Product TDS ppm as NaCl	Service Flow Rate gpm	Pressure psig Influent	Pressure psig Effluent	Total Gallons
	0919	105	47	69	30	380
17	1131	70	47	70	30	6580
	1324	80	43.7	72	30	11,520
	1403	120+	43.7	73	30	13,230
	1040	121	41	70	30	
18	1130	112	41	70	30	2050
	1308	112	41	70	30	6070
	1406	120	41	74	28	8560
	1455	74	43	76	30	430
19	0847	46	43	76	30	4420
	0940	116	43	76	30	6700
	1006	60	48.7	73	30	980
20	1057	54	48.7	74	30	3480
	1155	51	48.7	74	30	6310
	1455	112	48.7	74	30	15,060
	1043	70	44	75	30	790
21	1135	66	44	75	30	3070
	1328	81	44	76	31	8100
	1450	100	43	76	31	11,620
	1447	76	38	78	30	720
22	0758	53	38	77	30	4290
	0956	66	38	77	30	8840
	1104	118	38	77	30	11,420

Appendix D

TABLE D-1 ANION COLUMN CAPACITY

Run Number 5. Mode 3-2-1.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
0840	201	Cl	248	39			
		SO_4	386	5			
			634	44			
	Average		639	40	599	1330	6.6
0950	120	Cl	248	31			
		SO_4	396	5			
			644	36			
	Average		639	35	604	912	4.6
1038	110	Cl	248	30			
		SO_4	386	3			
			634	33			
	Average		626	29	601	1120	5.6
1137	99	Cl	237	25			
		SO_4	380	0			
			617	25			
	Average		590	26	564	1200	5.7
1240	92	Cl	208	23			
		SO_4	354	3			
			562	26			
	Average		587	33	554	987	4.6
1332	96	Cl	237	36			
		SO_4	375	3			
			612	39			
	Average		623	39	584	418	2.0
1354	102	Cl	248	36			
		SO_4	385	3			
			633	39			
	Average		662	66	596	684	3.4
1430	201	Cl	304	90			
		SO_4	386	3			
			690	93			

TABLE D-2 ANION COLUMN CAPACITY

Run Number 6. Mode 1-2-3.

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	237	35			
		SO_4	429	6			
			666	39			
	Average		666	42	626	1100	6.3
1001	175	Cl	237	28			
		SO_4	429	6			
			666	34			
	Average		631	32	599	894	4.5
1048	173	Cl	192	25			
		SO_4	400	4			
			592	29			
	Average		594	31	563	1200	5.6
1151	171	Cl	197	27			
		SO_4	394	6			
			591	33			
	Average		563	33	530	1140	5.1
1251	173	Cl	181	26			
		SO_4	354	7			
			535	33			
	Average		517	31	486	1140	4.6
1351	172	Cl	175	23			
		SO_4	323	5			
			498	28			
	Average		531	38	493	1230	5.1
1456	171	Cl	220	45			
		SO_4	343	3			
			563	48			
	Average		563	60	503	456	1.9
1520	167	Cl	220	68			
		SO_4	343	4			
			563	72			

TABLE D-3 ANION COLUMN CAPACITY

Run Number 7. Mode 3-2-1.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
0820	351	Cl	226	45			
		SO_4	438	7			
			664	52			
	Average		656	46	610	612	3.5
0854	191	Cl	209	35			
		SO_4	438	4			
			647	39			
	Average		638	40	598	630	3.1
0929	180	Cl	192	35			
		SO_4	437	6			
			629	44			
	Average		619	41	578	1640	7.9
1100	144	Cl	192	34			
		SO_4	416	6			
			608	40			
	Average		624	48	576	2560	12.3
1322	186	Cl	214	34			
		SO_4	426	21			
			640	55			
	Average		602	51	551	1300	6.0
1434	359	Cl	210	42			
		SO_4	354	5			
			564	47			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-4 ANION COLUMN CAPACITY

Run Number 8. Mode 1-2-3.

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	271	66			
		SO_4	417	6			
			688	72			
	Average		688	72	619	170	0.9
0837	270	Cl	271	65			
		SO_4	417	6			
			688	71			
	Average		643	71	572	900	4.3
0920	241	Cl	254	64			
		SO_4	354	6			
			608	70			
	Average		594	81	513	1430	6.1
1044	232	Cl	226	85			
		SO_4	354	6			
			580	91			
	Average		575	101	474	1070	4.2
1147	239	Cl	226	104			
		SO_4	343	6			
			569	110			
	Average		575	125	450	1560	5.9
1319	247	Cl	226	133			
		SO_4	354	6			
			580	139			
	Average		580	173	307	2140	5.5
---	360	Cl	226	201			
		SO_4	354	6			
			580	207			
	Average						
		Cl					
		SO_4					

TABLE D-5 ANION COLUMN CAPACITY

Run Number 9. Mode 3-2-1.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	243	0			
		SO_4	411	11			
			654	11			
	Average		654	11	643	340	1.8
0940	176	Cl	243	0			
		SO_4	411	11			
			654	11			
	Average		660	10	650	1090	5.9
1044	123	Cl	240	0			
		SO_4	426	8			
			666	8			
	Average		665	7	658	2440	13.4
1308	91	Cl	220	0			
		SO_4	404	6			
			624	6			
	Average		594	3	591	1770	8.7
1452	86	Cl	209	0			
		SO_4	354	0			
			563	0			
	Average		594	43	551	2340	10.7
0640	146	Cl	288	85			
		SO_4	377	0			
			665	85			
	Average		665	110	555	1310	6.6
---	360	Cl	288	134			
		SO_4	377	0			
			665	134			
	Average						
		Cl					
		SO_4					

TABLE D-6 ANION COLUMN CAPACITY

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$ Ion	In	Out	Δ	Gallons	Pounds Removed as $CaCO_3$
Run Number 10. Mode 1-2-3.							
---	360	Cl	350	35			
		SO_4	432	0			
			782	35			
	Average		782	33	749	558	3.5
0800	140	Cl	350	30			
		SO_4	432	0			
			782	30			
	Average		706	33	673	1780	10.0
0939	102	Cl	333	30			
		SO_4	296	5			
			629	35			
	Average		644	175	469	2900	11.3
1200	258	Cl	357	305			
		SO_4	302	9			
			659	314			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-7 ANION COLUMN CAPACITY

Run Number 11. Mode 3-2-1.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	306	78			
		SO_4	348	3			
			654	81			
	Average		654	75	579	812	3.9
1015	244	Cl	306	69			
		SO_4	348	3			
			654	72			
	Average		657	61	596	1710	8.5
1150	199	Cl	307	47			
		SO_4	333	3			
			640	50			
	Average		645	76	569	2500	11.9
1409	178	Cl	302	87			
		SO_4	348	8			
			650	95			
	Average		661	236	425	3000	10.6
0900	392	Cl	324	348			
		SO_4	348	29			
			672	377			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-8 ANION COLUMN CAPACITY

Run Number 12. Mode 1-2-3.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
1000	295	Cl	330	113			
		SO_4	343	3			
			673	116			
	Average		665	163	502	7560	31.7
1156	297	Cl	324	207			
		SO_4	333	3			
			657	210			
	Average		678	226	452	1000	3.9
---	360	Cl	326	239			
		SO_4	374	3			
			700	242			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO4					

TABLE D-9 ANION COLUMN CAPACITY

Run Number 13. Mode 3-2-1.

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
0844	373	Cl	327	175			
		SO_4	340	4			
			667	179			
	Average		658	182	476	4370	17.4
1016	346	Cl	314	180			
		SO_4	335	4			
			649	184			
	Average		652	199	453	3320	12.6
1126	380	Cl	310	211			
		SO_4	345	3			
			655	214			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-10 ANION COLUMN CAPACITY

Run Number 14. Mode 1-2-3.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	309	0			
		SO_4	343	3			
			652	3			
	Average		652	3	649	720	3.9
1016	230	Cl	309	0			
		SO_4	343	3			
			652	3			
	Average		651	3	648	3000	16.2
1127	196	Cl	302	0			
		SO_4	348	3			
			650	3			
	Average		664	144	520	5780	25.1
1344	339	Cl	292	281			
		SO_4	385	4			
			677	285			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-11 ANION COLUMN CAPACITY

Run Number 15. Mode 3-2-1.

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	320	48			
		SO_4	333	0			
			653	48			
	Average		653	48	605	645	3.3
0807	244	Cl	320	47			
		SO_4	333	0			
			653	47			
	Average		657	47	610	4590	23.4
0954	156	Cl	313	42			
		SO_4	348	4			
			661	46			
	Average		660	56	604	4160	21.0
1130	129	Cl	310	61			
		SO_4	348	4			
			658	65			
	Average		653	200	453	3050	11.5
1240	313	Cl	299	331			
		SO_4	348	4			
			647	335			
	Average		647	372	275	645	1.5
---	360	Cl	299	404			
		SO_4	348	4			
			647	409			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-12 ANION COLUMN CAPACITY

Run Number 16. Mode 1-2-3.

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	314	86			
		SO_4	348	4			
			662	90			
	Average		662	85	577	963	4.6
0946	276	Cl	314	75			
		SO_4	348	4			
			662	79			
	Average		661	83	578	2580	12.5
1045	214	Cl	316	83			
		SO_4	343	4			
			659	87			
	Average		653	86	567	3190	15.1
1158	200	Cl	313	80			
		SO_4	333	4			
			646	84			
	Average		643	203	440	3280	12.1
1313	349	Cl	307	317			
		SO_4	333	4			
			640	321			
	Average		640	385	255	209	0.5
---	360	Cl	307	445			
		SO_4	333	4			
			640	449			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-13 ANION COLUMN CAPACITY

Run Number 17. Mode 3-2-1.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	312	72			
		SO_4	332	4			
			644	76			
	Average		644	76	568	380	1.8
0919	260	Cl	312	71			
		SO_4	332	4			
			644	75			
	Average		654	76	578	6200	29.9
1131	198	Cl	306	73			
		SO_4	358	3			
			664	76			
	Average		654	116	538	4940	22.2
1324	213	Cl	300	151			
		SO_4	343	4			
			643	155			
	Average		649	261	388	1710	5.5
1403	390	Cl	307	362			
		SO_4	348	4			
			655	366			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-14 ANION COLUMN CAPACITY

Run Number 18. Mode 1-2-3.

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
1040	254	Cl	323	113			
		SO_4	370	4			
			693	117			
	Average		677	121	556	2050	9.5
1130	255	Cl	313	120			
		SO_4	348	4			
			661	124			
	Average		664	239	425	4018	14.2
1308	422	Cl	312	350			
		SO_4	364	4			
			676	354			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-15 ANION COLUMN CAPACITY

Run Number 19. Mode 3-2-1.

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	301	0			
		SO_4	348	1			
			649	1			
	Average		674	1	673	430	2.4
1455	170	Cl	351	0			
		SO_4	348	1			
			699	1			
	Average		699	45	654	3990	21.8
0847	149	Cl	351	85			
		SO_4	348	3			
			699	88			
	Average		689	281	408	2280	7.8
0940	419	Cl	341	470			
		SO_4	338	3			
			679	473			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-16 ANION COLUMN CAPACITY

Run Number 20. Mode 1-2-3.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	334	0			
		SO_4	374	0			
			708	0			
	Average		708	0	708	976	5.8
1006	177	Cl	334	0			
		SO_4	374	0			
			708	0			
	Average		751	0	751	2490	15.6
1057	166	Cl	294	0			
		SO_4	406	0			
			794	0			
	Average		745	2	743	2830	17.5
1155	156	Cl	322	0			
		SO_4	374	4			
			696	4			
	Average		669	185	484	8760	34.4
1455	468	Cl	298	362			
		SO_4	343	3			
			641	365			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-17 ANION COLUMN CAPACITY

Run Number 21. Mode 3-2-1.							
Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	305	40			
		SO_4	379	4			
			684	44			
	Average		684	42	642	790	4.2
1043	196	Cl	305	35			
		SO_4	379	4			
			684	39			
	Average		665	37	645	2280	12.3
1135	187	Cl	302	31			
		SO_4	343	3			
			645	34			
	Average		671	38	633	5030	26.6
1328	201	Cl	302	37			
		SO_4	395	4			
			697	41			
	Average		667	179	486	3520	14.3
1450	300	Cl	298	297			
		SO_4	348	0			
			646	297			
	Average		646	314	332	1380	5.0
---	360	Cl	298	330			
		SO_4	348	0			
			646	330			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

TABLE D-18 ANION COLUMN CAPACITY

Run Number 22. Mode 1-2-3.

Time	Product micromhos/cm	First Anion Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
---	360	Cl	319	40			
		SO_4	364	3			
			683	43			
	Average		656	42	614	720	3.7
1447	177	Cl	287	37			
		SO_4	343	3			
			630	40			
	Average		664	41	623	3570	18.5
0758	146	Cl	335	39			
		SO_4	364	4			
			699	43			
	Average		678	59	619	4550	23.5
0956	171	Cl	324	73			
		SO_4	332	2			
			656	75			
	Average		670	229	441	2580	9.5
1104	365	Cl	319	380			
		SO_4	364	3			
			683	383			
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					
	Average						
		Cl					
		SO_4					

Appendix E

TABLE E-1 CATION COLUMN CAPACITY

Run Number 5. Mode 3-2-1.							
Time	Product micromhos/cm	First Cation Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
0840	201	Na	546	37			
		K	29	1			
		TH	270	10			
			845	48			
	Average		838	46	792	1330	8.8
0950	120	Na	534	40			
		K	28	1			
		TH	266	2			
			828	43			
	Average		818	42	776	912	5.9
1038	110	Na	513	37			
		K	26	1			
		TH	268	2			
			807	40			
	Average		808	37	771	1120	7.2
1137	99	Na	513	33			
		K	26	1			
		TH	270	0			
			809	34			
	Average		809	35	774	1200	7.8
1240	92	Na	513	35			
		K	26	1			
		TH	270	0			
			809	36			
	Average		804	37	767	987	6.3
1332	96	Na	503	37			
		K	26	1			
		TH	270	0			
			799	38			
	Average		815	46	769	418	2.7
1354	102	Na	513	49			
		K	26	1			
		TH	292	4			
			831	54			
	Average		848	56	792	684	4.5

TABLE E-1 CATION COLUMN CAPACITY (continued)

Run Number 5 (con't.). Mode 3-2-1.							
Time	Product micromhos/cm	First Cation Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out	Δ		
1430	201	Na	513	49			
		K	26	2			
		TH	286	6			
			825	57			
	Average						
		Na					
		K					
		TH					
	Average						
		Na					
		K					
		TH					
	Average						
		Na					
		K					
		TH					
	Average						
		Na					
		K					
		TH					
	Average						
		Na					
		K					
		TH					
	Average						
		Na					
		K					
		TH					
	Average						
		Na					
		K					
		TH					

TABLE E-2 CATION COLUMN CAPACITY

Run Number 6. Mode 1-2-3.

Time	Product micromhos/cm	First Cation Column mg/l as $CaCO_3$				Gallons	Pounds Removed as $CaCO_3$
		Ion	In	Out			
1001	175	Na	512	42			
		K	28	2			
		TH	272	4			
			812	48			
	Average		802	45	757	1994	12.6
1048	173	Na	491	40			
		K	27	1			
		TH	274	0			
			792	41			
	Average		786	42	744	1200	7.5
1151	171	Na	491	42			
		K	27	1			
		TH	262	0			
			780	43			
	Average		790	45	745	1140	7.1
1251	173	Na	512	42			
		K	26	1			
		TH	262	4			
			800	47			
	Average		795	46	749	1140	7.1
1351	172	Na	491	40			
		K	26	1			
		TH	272	2			
			789	43			
	Average		783	43	740	1230	7.6
1456	171	Na	491	42			
		K	26	1			
		TH	260	0			
			777	43			
	Average		777	48	729	456	2.8
1520	167	Na	491	51			
		K	26	2			
		TH	260	0			
			777	53			